STAFF REPORT

SUPPLY AND COST OF ALTERNATIVES TO MTBE IN GASOLINE

TECHNICAL APPENDICES

Refinery Modeling Task 2:
Calibration of Refinery Model

DECEMBER 1998

CALIFORNIA
ENERGY
COMMISSION

Pete Wilson, *Governor*

P300-98-013H

Evaluating the Cost and Supply of Alternatives to MTBE in California's Reformulated Gasoline

Project Report

REFINERY MODELING

Task 2: CALIBRATION OF THE REFINERY MODEL

Prepared for

California Energy Commission

by

MathPro Inc.

under

Subcontract No. CM6006W3

June 24, 1998

MathPro, Inc.

P.O. Box 34404
West Bethesda, Maryland 20827-0404
301-951-9006

TABLE OF CONTENTS

1.

1. INTRODUCTION

MathPro Inc. submits this report to the California Energy Commission pursuant to Task 2 (for the Refinery Modeling Subcontractor) of Subcontract CM6006W3 (Contract 500-96-012). Task 2 calls for calibration of the California statewide aggregated base case refinery model.

We developed a special variant of our refinery LP model (ARMS), whose outputs match key elements of the operations of the California refineries in the aggregate, as reported for Summer 1997. The calibration process involved:

- Developing a detailed description of the performance of the gasoline-producing refineries in California in Summer 1997, on the basis of refining principles and data from various sources (including the special survey conducted by CEC); and then

- Adjusting technical coefficients in the ARMS database (e.g., process yields, blendstock properties, etc.) and adding new elements to the ARMS model statement (e.g., processes, process operating modes, etc.) until the ARMS model yielded outputs (solutions) that closely match reported refining operations, with respect to crude slate, product volumes, product properties, and capacity utilization.

The modified and new elements will remain in the ARMS model throughout Task 3 – analysis of the various scenarios delineated in the Task 1 report.
2.

CALIBRATION CASE

2.1 Calibrating the Refinery Model

Calibration demonstrates the validity of the refinery LP model (ARMS) for the study at hand and establishes a base case for use in subsequent analysis. Calibration involves: (1) establishing an accurate representation of refining operations, in this case the aggregate operations of California gasoline-producing refineries; and (2) adjusting elements of the ARMS database, so that the ARMS model yields solution values that match with sufficient precision certain key measures of refinery operations.

We relied on information from publicly available documents, the CEC refinery survey, and interviews with refiners to characterize aggregate refinery operations for the 1997 Summer season in terms of:

- process capacities,
- crude oil slate,
- product slate,
- gasoline grade splits,
- prices for crude oil and refined products,
- product specifications and average properties for California RFG, Arizona RFG, and conventional gasoline; and
- product specifications and average properties for jet fuel and diesel fuel

The measures of refining operations we focused on when calibrating ARMS include:

- capacity utilization of various refining processes, particularly the major conversion units (coking, fluid cat cracking, and hydrocracking),
- product volumes,
- marginal refining costs at observed product volumes,
- marginal costs of product specifications,
- California RFG properties (as influenced by the Predictive Model), and
- jet fuel and diesel fuel properties.

2.2 Calibration Results

Our characterization of aggregate California refining operations, along with the calibration results are shown in Exhibits 1 through 12 (at the end of this report). In general, the key outputs of the ARMS aggregate model closely match the operations of the aggregate California refining sector.

The exhibits are as follows.

- **Exhibits 1.1** and **1.2** deal with process unit capacities and capacity utilization.

  Exhibit 1.1 shows (1) aggregate capacity, capacity utilization, and throughput, by process, as reported by the CEC survey, the API/NPRA survey (July 1997), the 1997 *Oil & Gas Journal* survey, and the 1997 DOE *Petroleum Supply Annual* and (2) the aggregate capacity profile that we established in ARMS for the calibration.

  Exhibit 1.2 shows (1) our estimates of the aggregate capacity profile, capacity utilization, and throughput, by process (**Reported/Derived**) and (2) the throughput and capacity utilization profiles generated by the ARMS model (**Calibration**). Of the fields labeled **Calibration**, **Capacity** denotes input to the ARMS model and **Thruput** and **Cap. Util.** denote outputs. The latter two fields show how the ARMS model uses the available aggregate capacity.

- **Exhibits 2.1**, **2.2**, and **2.3** deal with the crude oil slate.

  Exhibit 2.1 shows volumes and properties of domestic and imported crude oils run by the California refineries in Summer 1997, as reported by the CEC survey.

  Exhibit 2.2 shows volumes and properties of imported crude oils run by California refineries in 1997, as reported by DOE.

  Exhibit 2.3 characterizes the crude slate input to the ARMS model. In particular, it shows the volumes (K bbl/day), yields (of straight run fractions), assay distillations, and sulfur contents of the three constituents of the crude oil slate represented in ARMS: Alaskan North Slope (ANS), a domestic composite, and a foreign composite. The domestic and foreign composites have the volume-weighted average properties of, respectively, the California crudes and the imported crudes run by California refineries in Summer 1997.

- **Exhibit 3** deals with the full set of refinery *inputs* – crude oils, oxygenates, unfinished oils, fuel, and other inputs. The **Volume** and **Price** fields labeled **Calibration** denote outputs of the ARMS model – respectively, the computed volumes and marginal values (shadow prices) of refinery inputs.

- **Exhibit 4** deals with the full set of refinery *outputs* – including three gasoline classes (CARB RFG, Arizona RFG, and conventional), CARB diesel, EPA diesel, jet fuel, LPG, and other refined products. The **Volume** and **Price** fields labeled **Calibration** denote outputs of the ARMS model – respectively, the computed volumes and marginal values (shadow prices) of refinery outputs.

- **Exhibits 5.1**, **5.2**, and **5.3** deal with gasoline properties, by class and grade.

  Exhibit 5.1 shows the properties, by class and grade, of gasolines produced in Summer 1997, as reported by the CEC survey. The reported properties include octane, the

Predictive Model properties, API gravity, butane and pentane content, ASTM distillation, and oxygenate content.

Exhibit 5.2 shows similar information on gasolines produced in Summer 1996, as reported by the API/NPRA survey.

Exhibit 5.3 compares the surveyed gasoline properties presented in the two preceding exhibits with the corresponding computed properties. For each gasoline class, the field labeled **Calibration** denotes outputs of the ARMS model – computed average properties of the indicated gasoline class.

Exhibit 5.3 also shows the emissions performance of each gasoline class – based on both surveyed average properties and computed average properties from the ARMS model. We computed these values using the CARB Predictive Model.

- **Exhibits 6.1**, **6.2**, **6.3**, and **6.4** deal with the ASTM distillation curves for the various gasoline classes and for the entire gasoline pool. Each exhibit shows – for a particular gasoline class – distillation curve(s) drawn from survey data (CEC and API/NPRA) and the distillation curve output by the ARMS model.

  Distillation curves output by the ARMS model reflect the distillation curves of individual gasoline blendstocks (e.g., FCC gasoline, reformate, alkylate) registered in the ARMS database. The distillation curves in the ARMS database were among the technical coefficients modified in the calibration effort.

- **Exhibit 7** deals with gasoline composition, by class. All of the values shown in this exhibit are outputs of the ARMS model.

- **Exhibit 8** deals with distillate product properties. The exhibit shows properties of jet fuel, CARB diesel fuel, and EPA diesel fuel produced in California. The reported properties include API gravity, aromatics content, sulfur content, cetane number (clear), and ASTM distillation. The exhibit compares surveyed distillate product properties with the corresponding computed properties. For each distillate product, the field labeled **Calibration** denotes outputs of the ARMS model – computed average properties of the indicated distillate product.

- **Exhibit 9.1** shows the distillation curves for two classes of FCC gasolines – low sulfur and high sulfur – as reported in the CEC survey and as represented in ARMS. **Exhibit 9.2** shows how the high sulfur FCC gasoline is fractionated in ARMS and the effect of subsequent desulfurization and olefins saturation on the distillation curves of those streams.

- **Exhibits 10.1 and 10.2** show: (1) combinations of T_{50}/E_{200} and T_{90}/E_{300} reported in the CEC and API/NPRA surveys; (2) revised combinations of T_{90}/E_{300} such that the E_{300}s are more consistent with reported distillation curves; (3) linear relationships for

T_{50}/E_{200} and T_{90}/E_{300} developed by EPA; and (4) linear relationships for T_{50}/E_{200} and T_{90}/E_{300} developed by MathPro and used in this study.

- **Exhibit 11** shows (a subset of) gasoline blendstocks in ARMS, properties and octanes for such blendstocks, and the composition of the three types of gasoline in the Calibration Case.

- **Exhibit 12** provides a summary of modifications and enhancements made to ARMS for this study.

3.0 METHODOLOGY

This section discusses the approach, assumptions, and modifications and enhancements to ARMS for calibrating ARMS to represent the aggregate operations of the California refining sector.

3.1 Unit Operating Rates

We calibrated ARMS to match the operating rates (thoughput) of conversion units – coking, fluid cat cracking, and hydrocracking – through the following iterative procedure.

- Fixed aggregate crude oil purchases at the reported throughput for atmospheric distillation.

- Increased purchases of residual oil until coker throughput matched reported throughput.

- Added purchases of heavy gas oil until total purchases of unfinished oils were similar to reported purchases and the combination of FCC and gas oil hydrocracking was consistent with information from the CEC survey.

- Required the solvent deasphalting unit to operate at full capacity and designated part of its output as FCC feed.

- Modified the capacity for gas oil hydrocracking until FCC throughput matched reported throughput.

- Initially capped distillate hydrocracking capacity such that the combined capacity of gas oil and distillate hydrocracking matched reported hydrocracking throughput; subsequently set distillate hydrocracking capacity equal to reported hydrocracking capacity less gas oil hydrocracking capacity established in ARMS.

In the final calibration case: (1) all resid boiling range (1050°+) material is processed by the cokers (primarily) and the solvent deasphalter; (2) all FCC clarified oil is processed by the cokers; (3) all gas oil boiling range (620° – 1050°) material is processed by the FCC unit (primarily) or the gas oil hydrocracker; (4) no distillate (500° – 620°) or resid (1050°+) material is processed by the FCC unit; (5) most light cycle oil, all coker distillate, some virgin distillate, and all heavy FCC gasoline fractionated out for T_{90} control is processed by the distillate hydrocracker; and (6) the gas oil hydrocracker would run additional material if allowed.

We adjusted the operating rates of other units as follows.

- TAME. Set a minimum on depentanization of FCC gasoline to provide feed for and insure operation of TAME units. (The minimum is based on the combined FCC capacity of the two refineries with TAME units.)

- Cat poly plant. Designated polymer gasoline as an aviation gasoline blendstock (and eliminated other streams as blendstocks) to insure operation of the small cat poly plant.

- Reforming. Represented all reforming capacity as medium pressure, i.e., 150 - 350 psi.

- Alkylation. Required investments in light ends processing to support any use of FCC olefin-maximizing catalysts. (Olefin-maximizing catalysts increase the availability of feeds for alkylation.) None was used in the Calibration Case.

- FCC feed hydrotreating. Required all FCC feed to be hydrotreated.

- FCC gasoline hydrotreater. Adjusted the extent of FCC gasoline hydrotreating by modifying: (1) the sulfur content of FCC gasolines; (2) the desulfurization and olefin saturation rates for the FCC gasoline hydrotreater (percent reductions in sulfur and olefins); and (3) the ratio of light feed to total FCC gasoline feed hydrotreated.

3.2 Crude Oil Slate

In characterizing the California crude oil slate, we used crude assays (for California crudes and ANS) supplied by Purvin & Gertz and crude assays (for foreign crudes) from public sources.

We used these assays to establish the ARMS representations of crude distillation yields and the relevant properties of crude oil fractions produced in the crude running unit. In this procedure, we characterize each crude as a set of crude oil fractions, which we select from a pre-defined set of crude oil fractions (each with a specific boiling range, API gravity, and sulfur content) in our database. For example, ARMS has five heavy gas oil fractions (800° - 1050°) and six vacuum resid fractions (1050° +), each defined by sulfur content and API gravity.

We used the crude oil volumes, sulfur contents, and API gravities reported in the CEC survey to develop the relative volumes of crude oils comprising the domestic (California) composite crude. Tha is, the domestic composite crude is a weighted average of ARMS representations of six California crudes – San Joaquin Heavy, San Joaquin Light, Line 63, Elk Hills, Wilmington, and OCS. Likewise, the foreign composite is a weighted average of foreign crudes represented in ARMS, with weights based on detailed data on crude oil imports reported by DOE (Exhibit 2.2).

The numbers at the bottom of Exhibit 2.3 represent the weighted average API gravity and sulfur content, drawn from the crude oil assays, weighted by the crude oils' volume fractions in the composite crudes. The corresponding numbers above the bottom set represent the API gravity and sulfur content of the composite crudes as represented in the ARMS model. These values are the volume-weighted averages of the API gravities and sulfur contents of the pre-defined crude fractions that we used to represent the crude oils.

The California crudes tend to have combinations of API gravity and sulfur content that do not match up as well with our pre-defined set of crude oil fractions as other crudes do. In particular, the California crudes tend to be unusually heavy given their sulfur content. Hence, when we select crude fractions that match on sulfur content, we end up with a set of fractions that is lighter than the actual California crudes. Further, the OCS crude has a higher sulfur content in the atmospheric resid boiling range (620° +) than any of our corresponding crude oil fractions. The end result is that our domestic composite crude matches the weighted average of California crudes in terms of the distillation curve, but is lighter and has somewhat lower sulfur content. This discrepancy has only minor effects on the Calibration Case and will have no material effect on the Task 3 analysis

3.3 Product Slate

We set limits for various refined products as follows:

Refined Product	Type of Limit
Propane	Upper bound
Propylene	Fixed
Butane	Lower bound
Mixed Butylenes	Upper bound
Aviation Gas	Fixed
Naphtha	Fixed
Gasoline	Fixed
Jet Fuel	Fixed
CARB Diesel	Fixed
EPA Diesel	Narrow range
Other Distillate	Fixed
Unfinished Oils	Open
Residual Oil	Open
Lubes & Waxes	Fixed
Sulfur	Open
Coke	Open

With conversion unit throughputs similar to those reported in surveys, ARMS initially produced more distillate products and less residual products and coke than reported. To bring the ARMS product slate more closely with the reported product slate we:

- Modified yields for delayed cokers to produce more coke and less coker gas.[1]

- Established an unfinished oil category as an outlet for light cycle oil used as cutter stock for residual oil blending and priced it such that (1) there is a small incentive to produce light cycle oil for this purpose and (2) all available resid boiling range material is processed by the cokers.

- Established a recipe blend (tar and kerosene) for a producing resid from heavy material produced by the solvent deasphalter.

- Added a new product category for "other distillate" – a low volume, high sulfur content, heavy distillate product.

The net result is that ARMS "produces" the reported volumes of the high-value refined products -- gasoline, jet fuel, and diesel fuel -- but less residual oil.

3.4 Shadow Values for Inputs and Refined Products

Shadow values for refinery inputs (e.g., crude oil and unfinished oils) indicate the marginal value in ARMS of an additional unit of input. Likewise, shadow values for refined products indicate the marginal cost in ARMS of increasing production by one unit.[2]

We did not set up the Calibration Case so that shadow values would match reported market prices for inputs and refined products. Instead, we constrained most inputs and refined product outputs to equal reported volumes.[3] In general, when refined product volumes are constrained to be equal to reported volumes, shadow values should be:

1. Higher for higher quality inputs (e.g., lighter, lower sulfur crudes should have higher shadow values than heavier, higher sulfur crudes and purchased blendstocks such as alkylate should have higher shadow values than gas oils).

2. Higher for refined products with tighter standards (e.g. CARB RFG should have a higher shadow value than Arizona RFG which, in turn, should have a higher shadow value than conventional gasoline).

---

[1] We initially included three types of cokers in the ARMS representation – delayed, fluid, and flexi. Because of discrepancies between surveys in designating coking capacity as fluid versus flexi, we treated all such capacity as fluid. This caused coke production to increase (above reported volumes) because flexi cokers produce substantially less coke than fluid cokers.

[2] The marginal costs in ARMS for refined products do *not* include capital charges associated with investments already made for existing process capacity.

[3] If no constraints are imposed on specific inputs or products, i.e., required volumes are "open," shadow values will equal the prices for those inputs and products (given that there is some volume of input or production).

3. Fairly close to reported market prices (averaged over time periods long enough to remove fluctuations caused by market disruptions).

As shown in Exhibits 3 and 4, shadow values for inputs and refined products in ARMS are consistent with these requirements.

3.5 Ratio Constraints

We used ratio constraints in the Calibration Case in two general ways:

- Minimize the extent of *cherry-picking*.

  Cherry-picking occurs when a refinery LP model selectively processes certain streams that in actual refineries are commingled with others and, in practice, cannot be processed separately. For example, ARMS includes a number of distinct distillate boiling range streams, each with a different sulfur content. Left to its own devices, ARMS (as would most refinery LP models) would select the high sulfur content streams to desulfurize and would not desulfurize low sulfur content streams. This leads to over-optimization, because actual refineries cannot segregate streams by sulfur content – they have to process a commingled stream.[4]

- Constrain the operations of specific process units in ARMS to be consistent with operations of those units in the California refining sector.

More specifically, we set ratio constraints such that:

1. Light gas oil streams (defined by API gravity and sulfur content) were processed in the gas oil hydrocracker in proportion to their relative volumes in the crude oil slate (with an adjustment for production of coker gas oil).

2. Light and heavy gas oils (defined by API gravity and sulfur content) were processed in the conventional FCC feed hydrotreater in proportion to their relative volumes in the crude oil slate (adjusted for gas oil produced by cokers and processed by the gas oil hydrocracker). The "deep" FCC feed hydrotreater processed all remaining gas oils.

3. Resid streams (defined by API gravity and sulfur content) were processed in the delayed and fluid cokers in proportion to their relative volumes in the crude oil slate. We did not impose constraints on coking of FCC-produced clarified oils.

4. Virgin distillate streams (defined by API gravity, sulfur content, and other properties) were processed in the distillate hydrocracker in proportion to their relative volumes in the

[4] Over-optimization denotes the tendency of refinery LP modeling to indicate higher aggregate profit contributions or lower incremental costs for a given refining operation than could occur in practice for a given set of refinery capital stock, product specifications, and market conditions.

crude oil slate.

5. Virgin heavy naphtha, kerosene, and distillate streams (defined by API gravity, sulfur content, and other properties) were processed in the distillate hydrotreater in proportion to their relative volumes in the crude oil slate. We did not impose ratio constraints on desulfurization of FCC-produced light cycle oil, nor on any dearomatized streams.

6. Light cycle oil can comprise only a small fraction of the distillate product pool. (The constraint is imposed by limiting desulfurization of light cycle oil to less than 2.3% of distillate hydrotreating throughput and preventing dearomatization of light cycle oil.) The net result of this and other modifications to ARMS is that no light cycle oil is blended to the distillate product pool in the Calibration Case.

7. The throughputs for the conventional and deep FCC feed hydrotreating units were in proportion to our estimate of the capacities of those units in the California refining sector.

8. FCC conversion rates were similar for low and high sulfur feeds.

9. At least 15% of the FCC gasoline treated to reduce olefins and sulfur was light FCC gasoline (to reflect that some refiners treat full-range FCC gasoline).

10. Fractionation of FCC gasoline and hydrocracking of the heavy ends (for T_{90} control) was in proportion to the relative volumes of FCC gasoline produced from conventional and deep hydrotreated FCC feeds.

3.6 FCC Gasoline Sulfur Control

ARMS, as configured for this study, controls the sulfur content of FCC gasoline through two routes – (1) deep hydrotreating of FCC feed and (2) conventional hydtrotreating of FCC feed in combination with FCC gasoline hydrotreating and olefins saturation.

Deep hydrotreating of FCC feed

About 53% of FCC feed hydrotreating capacity in California is capable of reducing the sulfur content of gas oils by over 95%. Data from the CEC survey and information provided by refiners indicates that FCC gasoline produced from FCC feeds desulfurized by such units has very low sulfur content, relatively high aromatics content, and low olefins content. We set these properties for FCC gasoline (at 70% conversion) as follows: sulfur – 60 ppm, aromatics – 33.1 vol%, and olefins – 11.6 vol%.

The only disposition in ARMS of FCC gasoline produced from deep hydrotreated feeds is gasoline blending, i.e, no further olefin control or desulfurization is allowed. However, we allow the heavy end (a 375°+ material – 11% by volume) of this FCC gasoline to be fractionated out and hydrocracked for T_{90} control.

Conventional hydtrotreating of FCC feed in combination with FCC gasoline hydrotreating and olefins saturation

About 47% of FCC feed hydrotreating capacity in California is capable of reducing the sulfur content of gas oils by about 85%. FCC gasoline produced from feeds subject to conventional desulfurization has a low sulfur content (by national standards), relatively low aromatics content, and high olefins content. We set these properties for FCC gasoline (at 70% conversion) as follows: sulfur – 400 ppm, aromatics – 27.0 vol%, and olefins – 32.6 vol%.

In ARMS, FCC gasoline produced from conventional hydrotreated FCC feed may be (1) blended directly to gasoline, (2) depentanized and then blended to gasoline, (3) split into light, medium, and heavy fractions for further desulfurization (and olefins control) and subsequent blending to gasoline; and (4) fractionated and the heavy end (a 375°+ material – 10% by volume) hydrocracked for T_{90} control.

We assumed that FCC gasoline desulfurization and olefin saturation (1) incur no yield loss and (2) reduce the sulfur and olefins content of FCC gasoline by the following percentages.

FCC Gasoline	Reduction in	
Fraction	Sulfur	Olefins
Light (22%)	75%	75%
Medium (50%)	90%	90%
Heavy (28%)	90%	90%

We also assumed that the octanes ((R+M)/2) of the FCC gasoline fractions are reduced as follows: light – 9 numbers; medium – 4 numbers; heavy – 1 number.

The distillation curves incorporated in ARMS for the two types of FCC gasolines (low sulfur and high sulfur) are shown in Exhibit 9.1. The distillation curves for the various FCC gasoline fractions and desulfurized fractions are shown in Exhibit 9.2.

3.7 T_{90} Control

ARMS has four options for controlling the T_{90} of gasoline.

- Fractionate FCC gasoline and hydrocrack the heavy end. This procedure was described in the preceding section. ARMS separated and hydrocracked about 22 K bbl/d of the heavy end of FCC gasoline. Thus, about 60% of produced FCC gasoline was fractionated for T_{90} control.

- Fractionate alkylate and distillate blend or hydrocrack the heavy end (10% of C4 alkylate, by volume).

- Fractionate heavy reformate and hydrocrack the heavy end (50% of heavy reformate, by volume).

- Fractionate 250°–325° naphtha to 250°–300° and 300°–325° fractions, followed by reform of the lighter fraction, and distillate blend the heavier fraction.

ARMS used only the first option to control T_{90} when capital charges for fractionation were included in the cost of T_{90} control. Consequently, we allowed ARMS to practice T_{90} control through FCC fractionation (with no capital charge). The other options remain available, but require building fractionation capacity. (With no capital charge assigned, fractionation of FCC gasoline and fractionation 250°-325° naphthas would have been used about equally for T_{90} control.)

3.8 Benzene Control

ARMS, as configured for this study, has two options for benzene control.

- Fractionate 160°-250° straight run naphtha to segregate benzene and benzene precursors in a 160°-175° cut, followed by either gasoline blending or isomerization of the 160°-175° cut and reforming of the 175°-250° cut (producing a light, low benzene content reformate). ARMS fractionates all light straight run naphtha and isomerizes the entire volume of 160°-175° straight run naphtha[5].

- Benzene saturation of reformate produced from 160°-250°, 250°-300°, and 250°-325° virgin naphthas, light coker naphtha, and medium and heavy hydrocrackate. ARMS sends most reformate, excluding reformate produced from the 175°-250° cut discussed above, to benzene saturation.

Thus, ARMS reduces the benzene content of reformate to nearly the full extent allowed by the naphtha fractionation and benzene saturation options, i.e., about 90% of all produced reformate is benzene-controlled. (We did not allow benzene extraction or benzene alkylation as benzene control options because California refineries do not practice those process options.)

3.9 Controlling Gasoline Properties

[5] ARMS does not have process options for fractionating light coker naphtha (after desulfurization) and medium hydrocrackate reformer feeds. This results in production of high benzene content, light reformates, most of which are treated in the benzene saturation unit, along with reformates produced from 250° + naphtha and heavy hydrocrackate feeds.

The calibration case includes three types of gasolines: CARB RFG, Arizona RFG, and conventional gasoline. We controlled the properties of Arizona RFG and conventional gasoline directly, i.e., we set pool properties for those gasolines equal to the pool properties reported in the CEC survey.[6] We did not control directly properties for CARB RFG. Rather, they were determined in ARMS by the interaction of (1) the techno-economics of gasoline production and (2) California's Predictive Model.[7]

ARMS incorporates a "reduced form" of California's Predictive Model. A reduced-form model attempts to capture in a simple mathematical structure the major relationships of a large or more complicated model. To be useful, a reduced form of the Predictive Model must: (1) calculate changes in emissions close to those calculated by the Predictive Model; (2) approximate the functional relationships between changes in emissions and specific gasoline properties, so that ARMS can identify the lowest cost CARB blend consistent with quality and emission performance constraints; and (3) be in a form that can be integrated into a refinery LP model. This last requirement can be satisfied if the reduced-form is "separable." A non-linear equation is separable if it has no terms that are a function of more than one variable. All linear equations are separable.

Two non-linear reduced-form versions of the Predictive Model are incorporated in ARMS. In the first version, the oxygen content of CARB RFG must be within a range 1.8 to 2.2 wt%. In the second version, the oxygen content of CARB RFG may vary between 0 and 1.8 wt%. In the Calibration Case, we used the version in which the pool oxygen content of CARB RFG must be within a range of 1.8 to 2.2 wt%. (We will estimate a third version of the Predictive Model for use in assessing ethanol blending in excess of 2.2 wt% oxygen.)

Developing the Reduced-Form Predictive Model

We developed the non-linear reduced-form models as follows:

1. We specified ranges for each Predictive Model property within which CARG RFG properties are likely to lie.

2. We generated 2000 sets of random "blends" (combinations of randomly generated sets of gasoline properties within the specified ranges) for each of the two versions of the Predictive Model and computed the corresponding emissions changes for VOCs, NOx, and toxics via the Predictive Model.

3. We used standard regression analysis to estimate separable, non-linear equations for

[6] The one exception is benzene content, which we limited to 0.80% because ARMS had difficulty in initial calibration runs in meeting the lower benzene levels of 0.64% and 0.73% reported for Arizona RFG and conventional gasoline, respectively. In subsequent calibration runs, ARMS could reduce benzene to lower levels, as evidenced by the presence of some uncontrolled reformate in the gasoline pool.

[7] The one exception is oxygen content, for which we set a minimum of 2.1 wt% to agree with reported values and the federal "averaging" minimum.

VOCs, NOx, and toxics.

The degree of fit and standard error of estimate for the reduced-form equations comprising the "fixed oxygen" (oxygen between 1.8 and 2.2%) and "variable oxygen" (oxygen content between 0 and 1.8%) versions of the Predictive Model are as follows.

	Fixed Oxygen		Variable Oxygen	
Emission	R^2	Std. Error	R^2	Std. Error
VOCs	.9985	.0968	.9990	.0576
NOx	.9983	.0233	.9980	.0273
Toxics	.9990	.1103	.9990	.1061

The Predictive Model is specified in terms of the T_{50} and T_{90} of gasoline (the temperature in °F at which 50% and 90% of gasoline is distilled off, respectively). In refinery LP models, however, gasoline blendstocks and blended gasolines generally are specified in terms of the percent off at various temperatures. For example, the E_{200} and E_{300} of a gasoline refer to the volume percents distilled off at 200°F and 300°F, respectively. Therefore, integration of the Predictive Model into a refinery LP model requires a translation between the two ways of specifying the distillation properties of gasoline.

EPA developed the following two equations for translating T_{50} to E_{200} and T_{90} to E_{300}:

$$E_{200} = 147.91 - 0.49 * T_{50}$$
$$E_{300} = 155.47 - 0.22 * T_{90}$$

EPA's equations are shown in Exhibits 10.1 and 10.2, along with reported combinations of T_{50}/E_{200} and T_{90}/E_{300} from the CEC Survey and the API/NPRA Survey. Because the EPA equations (1) do not pass through the points of equality between E values and T values, i.e. (200°F,50%) and (300°F,90%), and (2) are inconsistent with reported values from the two surveys (particularly for T_{90} and E_{300}), we estimated alternative equations for translating between E and T values.

The CEC and API/NPRA surveys report values for E_{300} that are slightly lower than indicated by the distillation curves defined by T_{10} through T_{90} values. We revised the E_{300} values slightly (increased them so they were consistent with the distillation curves) and estimated equations for translating between E and T values.

Our equations are shown below and also are graphed in Exhibits 10.1 and 10.2. (An initial equation for E_{300} also is shown in Exhibit 10.2.) These equations are implicitly incorporated in the reduced-forms of the Predictive Model integrated in ARMS.

$$E_{200} = 125.38 - 0.38 * T_{50}$$
$$E_{300} = 196.15 - 0.35 * T_{90}.$$

Integrating the Predictive Model in ARMS

Embedding the reduced-form models in ARMS involved three steps.

1. We developed a piecewise-linear approximation for each equation in the reduced-form model. (One can approximate the reduced-form to any desired accuracy by using shorter intervals and more line segments.)

2. For each piecewise-linear approximation, we created a set of new LP model variables, called Type 2 Special Ordered Sets, containing one variable for each break point, and an LP model equation summing the levels of all the variables in the set and setting the sum equal to 1.

3. For each gasoline pool property (e.g. aromatics content), we created an LP model equation connecting the gasoline blending sector of the model to the new reduced form sector and established a set of constraints imposing percentage emission reductions for each emission type.

This makes the linearized reduced form an integral part of the gasoline blending sector of the refinery LP model. The expanded ARMS model can be processed (generated, solved, and reported) in the conventional way. It treats the constraints imposed by the Predictive Model just as it does other techno-economic constraints.

Shadow Values for Gasoline Property Constraints

All constraints on gasoline properties set in the Calibration Case (either directly or through the Predictive Model) are tight, i.e., there is a cost associated with meeting each constraint for each type of gasoline – CARB RFG, Arizona RFG, and conventional gasoline. Shadow values for each property constraint are higher for CARB RFG and Arizona RFG than for conventional gasoline. Further, none of the shadow values is exceedingly large, indicating that ARMS is not improperly constrained by specific property constraints.

3.10 Gasoline Blendstock Properties

Exhibit 11 shows the ARMS blendstocks comprising each gasoline pool (CARB RFG, Arizona RFG, and conventional), along with the properties and octane of the blendstocks. We set the properties of the FCC gasolines to be consistent with the CEC survey results and to generate properties of California RFG in the Calibration Case that matched those reported in surveys. We reduced the sulfur content of most blendstocks to agree with sulfur levels reported in the CEC Survey. We modified the octane of hydrocrackates and the aromatics content of FCC gasoline and reformates to be consistent with the CEC survey. Finally, we modified the distillation curves of most blendstocks – C_{4s}, naphthas, hydrocrackates, alkylates, FCC gasoline, and reformates – such that the distillation curve for the entire gasoline pool “produced” by ARMS (a weighted average of CARB RFG, Arizona RFG, and conventional gasoline) closely tracked the pool distillation curve calculated using survey data.

3.11 Summary of Modifications to ARMS

Exhibit 12 provides a list of the modifications and enhancements made to ARMS in developing the Calibration Case and the purpose of each.

3.12 Summary of Revisions to Initial Calibration Case

CEC, WSPA, and other interested parties reviewed the draft Task 2 report detailing the results of our initial Calibration Case. In response to comments on the initial Calibration Case and our own internal review, we made the following revisions to the Calibration Case.

- Modified yields for the delayed coker (removed production of coker bottoms) and hydrocrackers (removed production of resid blending material).

- Modified the capacity for gas oil hydrocracking (so that FCC throughput agreed with reported volumes) and removed the capacity constraint on distillate hydrocracking set in the initial calibration work. (Distillate hydrocracking capacity is now equal to total reported hydrocracking capacity, minus capacity for light gas oil hydrocracking.)

- Modified ratio constraints controlling the FCC gasoline desulfurization unit such that 15% of FCC gasoline undergoing sulfur and olefins control must be light FCC gasoline. (Previously the constraint was set at 22%. The lower percentage reflects that some, but not all, refiners treat full-range FCC gasoline.)

- Established ratio constraints for the FCC unit so that conversion rates for low and high sulfur FCC feeds are similar. (We imposed ratio constraints because modifications made regarding the disposition of light cycle oil led to cherry-picking in the FCC unit, i.e., the conversion rate for high sulfur feed became substantially lower than the conversion rate for low sulfur feed.)

- Limited the extent to which light cycle oil is blended in distillate products (by imposing ratio constraints in the distillate desulfurization unit and preventing dearomatization of light cycle oils).

- Established a new distillate product to represent production of a small volume (15 K bbl/d) of heavy, high sulfur distillate material (and correspondingly reduced production of EPA diesel).

- Set up an unfinished oil product category for light cycle oil used as residual oil cutter stock.

- Set an upper limit of 4 K bbl/d for sales of mixed butylenes (consistent with DOE reported sales volumes).

- Represented all reforming as medium pressure (150 – 350 psi) rather than low pressure (< 150 psi).

- Reduced the octane of hydrocrackate to be more consistent with the CEC survey. (This increased reformer throughput and severity and caused a small volume of medium hydrocrackate, in addition to all heavy hydrocrackate, to be used as reformer feed.)

- Created a new blendstock to represent isomerate produced from 160-175° naphtha. (Previously, such production was represented by isomerate produced from C5-160° naphtha.)

- Revised the sulfur contents of oxygenates as follows: captive MTBE – 50 ppm; merchant MTBE – 10 ppm; and captive TAME – 50 ppm.

- Modified the distillation curves for medium, high-sulfur FCC gasoline. (They were incorrectly entered in ARMS in the previous Calibration Case.)

- Reduced the aromatics content of FCC gasoline to account for higher conversion in the new Calibration Case.

- Reduced the aromatics content of reformates to be more consistent with the CEC survey and more closely match gasoline pool properties.

- Modified the ARMS representation of the Predictive Model for the revised relationship between E300 and T90.

This series of modifications improved our representation in ARMS of the aggregate operations of the California refining sector.

Exhibit 1.1: Process Unit Capacity and Capacity Utilization of California Refineries, by Source

Type of Process	Process	Capacity Reported in Terms of	CEC Capacity (K bbl/d)	CEC Thru-put (K bbl/d)	CEC Cap. Util. (%)	API/NPRA* Capacity (K bbl/d)	API/NPRA* Cap. Util. (%)	OGJ Capacity (K bbl/d)	DOE Capacity (K bbl/sd)	DOE Thru-put (K bbl/d)	Calibration Capacity (K bbl/d)
Crude Distillation	Atmospheric	Feed	1,845	1,724	93.5	1,545	89.0	1,867	1,898		1,845
	Vacuum	Feed	1,006	919	91.4	868	86.6	1,038	1,040		-
Conversion	Coking	Feed	487	451	92.6	385	87.0	449	505	424	488
	Delayed	Feed	390	357	91.5			361	408		390
	Fluid & Flexi	Feed	98	95	97.2			88	97		98
	Fluid Cat Cracking	Feed	655	615	93.9	596	88.3	612	652	623	655
	Hydrocracking	Feed	393	307	78.1	470	71.0	349	426	344	393
	Visbreaking	Feed				0		10	5		-
Upgrading	Alkylation	Product	159	143	89.7	148	84.4	142	153		159
	Dimersol	Product	nr	nr	-	5	58.1	2			5
	Pen/Hex Isomerization	Product	112	90	80.6	81	75.6	80	71		80
	Polymerization	Product	nr	nr	-	5	94.4	6			6
	Reforming	Feed	418	317	75.9	368	66.3	407	433		418
Oxygenate Prod.	MTBE	Product	12	11	91.4	18	58.1	9			12
	TAME	Product	nr	nr	-	-	-	5			5
Hydrotreating	Naphtha Feed	Feed	406	346	85.2	356	79.3	422	442		410
	Straight Run	Feed	150	127	84.8			78			150
	Reformer Feed	Feed	256	219	85.4			344			260
	Kerosene & Distillate	Feed	398	305	76.6	352	70.4	422	404		398
	Distillate Dearomatization	Feed	78	57	74.0	89	64.2				125
	FCC Feed/Heavy Gas Oil	Feed	667	582	87.2	583	76.7	454	686		655
	Mid-Dist. Hydrorefining	Feed						41			
	Selective Hydrotreating	Feed				104	81.9				
	Other Hydrotreating	Feed						169	146		
	FCC Gasoline	Feed	101	80	78.9						101
	Benzene Saturation	Feed	61	41	67.7						61
	Nap. Olefin or Benzene Sat.	Feed						47			
Hydrogen (MM scf/d)	Total	Product	1,161	921	79.4	894	73.5	1,063	1,110		1,160
	Refinery-owned	Product	983	764	77.7	890	73.5	1,025	1,110		
	3rd party-owned	Product	174	155	89.4	-	-	35			
	Purification	Feed	51	28	54.9	48	73.9				
	Purification	Product						4			
Other	Aromatics Plant	Product	nr	nr	-	5	89.2				-
	Butane Isomerization	Feed	18	18	100.0	10	87.8	11	5		18
	Lube Oil	Product	nr	nr	-			21	29		25
	Solvent Deasphalting	Feed	nr	nr	-	50	62.0		50		50
	Sulfur Recovery (K tons/d)	Product	4.7	3.7	78.5	3.4	48.2	3	4		6
	Tail Gas Recovery (K tons/d)	Product	0.2	0.1	61.9	0.2	61.6				

* Ten refineries in survey.
nr -- not reported.
Note: CEC -- Summer 1997; API/NPRA -- Summer 1996; OGJ -- as of Jan. 1998; and DOE -- capacity as of Jan. 1997 and throughput for Summer 1997.

Sources: 1998 California Refinery Survey; 1996 API/NPRA Survey of Refining Operations and Product Quality, July 1997;
Oil & Gas Journal, Dec. 22, 1997, pp 79-80; Tables 38 & 39, *Petroleum Supply Annual 1996*, Volume 1, Energy Information Administration; and PIIRA Reports for Summer 1997.

Exhibit 1.2: Process Unit Capacity and Capacity Utilization -- Calibration

		Source		Reported/Derived			Calibration		
Type of Process	Process	Capacity	Thru-put/Cap. Util.	Capacity (K bbl/d)	Thru-put (K bbl/d)	Cap. Util. (%)	Capacity (K bbl/d)	Thru-put (K bbl/d)	Cap. Util. (%)
Crude Distillation	Atmospheric	CEC	CEC	1,845	1,724	93.5	1,845	1,725	93.5
	Vacuum	CEC	CEC	1,006	919	91.4	-		
Conversion	Coking	CEC	DOE	487	424	87.0	488	420	86.1
	Delayed	CEC	Derived	390	329	84.5	390	322	82.6
	Fluid & Flexi	CEC	CEC	98	95	97.2	98	98	100.0
	Fluid Cat Cracking	CEC	DOE	655	623	95.2	655	623	95.1
	Hydrocracking	CEC	DOE	393	344	87.6	393	371	94.5
	Distillate	-	-				263	241	91.8
	Gas Oil	-	-				130	130	100.0
Upgrading	Alkylation	CEC	CEC	159	143	89.7	159	148	93.2
	Dimersol	API/NPRA	API/NPRA	5	3	58.1	5	0	0.0
	Pen/Hex Isomerization	OGJ	API/NPRA	80	60	75.6	80	59	73.3
	Polymerization	API/NPRA	API/NPRA	5	5	94.4	6	5	83.3
	Reforming	CEC	CEC	418	317	75.9	418	285	68.1
Oxygenate Prod.	MTBE	CEC	CEC	12	11	91.4	12	12	100.0
	TAME	OGJ	-	5	-	-	5	2	33.8
Hydrotreating	Naphtha Feed	CEC	CEC	406	346	85.2	410	309	75.4
	Straight Run	CEC	CEC	150	127	84.8	150	64	42.6
	Reformer Feed	CEC	CEC	256	219	85.4	260	245	94.2
	Kerosene & Distillate	CEC	CEC	398	305	76.6	398	306	76.8
	Distillate Dearomatization*	CEC	CEC	78	57	74.0	125	95	75.9
	FCC Feed/Heavy Gas Oil	CEC	CEC	667	582	87.2	655	620	94.6
	Conventional	-	-					297	
	Deep	-	-					322	
	FCC Gasoline	CEC	CEC	101	80	78.9	101	70	69.7
	Benzene Saturation	CEC	CEC	61	41	67.7	61	53	86.9
Hydrogen (MM scf/d)		CEC	CEC	1,161	921	79.4	1,160	1,082	93.3
Other	Aromatics Plant	API/NPRA	API/NPRA	5	4	89.2	-		
	Butane Isomerization	CEC	CEC	18	18	100.0	18	18	100.0
	Lube Oil	OGJ	-	21	-		25	22	88.0
	Solvent Deasphalting	DOE	API/NPRA	50	31	62.0	50	50	100.0
	Sulfur Recovery (K tons/d)	CEC	CEC	4.7	3.7	78.5	6	5	86.3
	Tail Gas Recovery (K tons/d)	-	-						
Fractionation	Debutanization						open	178	-
	Depentanization						60	60	100.0
	Naphtha Splitter (Benz. Prec.)						open	97	-
	Naphtha Splitter (T90 Ctrl.)						open	0	
	Alkylate Splitter						open	0	
	Heavy Reformate Splitter						open	0	
	FCC Naphtha Splitter						open	135	-
	FCC Naphtha T90 Control						open	141	-
Operating Indices	FCC Conversion	API/NPRA				75.4			74.1
	Reformer Severity	-							99.9

* In ARMS, distillate dearomatization occurs in a stand-alone unit that takes feeds only from the distillate hydrotreater. However, some California refineries may have combined units with capacity reported under distillate hydrotreating. This may account for the difference in throughput for distillate dearomatization in ARMS versus that reported in surveys.

Sources: Exhibit 1.1 and ARMS Calibration Results.

Exhibit 2.1: California Crude Oil Inputs

Summer 1997

Crude Oil	Volume (K bbl/d)	Sulfur (wt%)	API Gravity	Specific Gravity
Alaskan	**657**	**1.03**	**28.2**	**0.886**
California	**866**	**1.81**	**18.2**	**0.945**
Kern River	113	1.22	13.4	0.977
Outer Continental Shelf	113	4.42	19.8	0.935
San Joaquin Heavy	301	1.31	13.2	0.978
San Joaquin Light	69	0.75	28.7	0.883
Other	270	1.81	23.2	0.915
Imports	**234**	**1.47**	**28.9**	**0.882**
Loreto	32	1.17	20.0	0.934
Maya	11	3.55	21.2	0.927
Oriente	27	1.18	25.8	0.899
Other	164	1.44	31.9	0.866
Total	**1,757**	**1.48**	**23.2**	**0.915**

Source: 1998 California Refinery Survey.

Exhibit 2.2: California Crude Oil Imports, by Country

1997

Country of Origin	Volume (K bbl)	Volume (K bbl/d)	Sulfur (wt %)	API Gravity	Specific Gravity
Argentina	1,816	5.0	0.45	25.4	0.902
	1,028	2.8	0.19	36.0	0.845
Australia	1,140	3.1	0.04	47.1	0.792
Canada	1,133	3.1	2.58	23.3	0.914
	130	0.4	0.70	45.8	0.798
Chile	2,116	5.8	0.33	35.9	0.846
	200	0.5	0.02	44.6	0.804
China	1,874	5.1	0.10	32.3	0.864
Colombia	850	2.3	1.21	28.9	0.882
Ecuador	9,232	25.3	1.18	25.2	0.903
Indonesia	2,039	5.6	0.07	33.5	0.857
Iraq	12,907	35.4	2.00	33.9	0.855
Kuwait	526	1.4	3.90	18.7	0.942
	7,830	21.5	2.50	31.3	0.869
Malaysia	579	1.6	0.02	45.2	0.801
Mexico	3,493	9.6	3.25	21.9	0.922
	501	1.4	1.50	32.8	0.861
Oman	1,271	3.5	0.80	33.2	0.859
Peru	5,562	15.2	1.01	20.2	0.933
Saudi Arabia	5,286	14.5	1.93	32.0	0.865
Venezuela	2,307	6.3	2.50	11.5	0.990
	628	1.7	1.05	12.5	0.983
	363	1.0	1.00	35.8	0.846
	219	0.6	0.10	58.0	0.747
Total	**63,030**	**172.7**	**1.60**	**28.8**	**0.883**

Source: DOE 1997 Import Data.

Exhibit 2.3: California Crude Oil Slate: Fractions, Properties, and Distillation Curves

Fractions & Properties	Alaskan North Slope	Domestic Composite	Foreign Composite	Total
Volume (K bbl/d)	645	850	230	1,725
CRUDE FRACTIONS				
LPGs:				
Ethane	0.0000	0.0001	0.0010	0.0002
Propane	0.0010	0.0009	0.0039	0.0013
Isobutane	0.0086	0.0005	0.0030	0.0039
Butane	0.0237	0.0034	0.0094	0.0118
Naphthas:				
Very Light (C5-160)	0.0434	0.0170	0.0443	0.0305
Light (160-250)	0.0843	0.0349	0.0574	0.0564
Medium (250-325)	0.0689	0.0302	0.0626	0.0490
Heavy (325-375)	0.0288	0.0245	0.0434	0.0286
Middle Distillates:				
Kerosene (375-500)	0.1013	0.0895	0.1138	0.0971
Distillate (500-620)	0.1197	0.1098	0.1206	0.1150
Atmospheric Resid:				
Light gas oil (620-800)	0.1603	0.1798	0.1650	0.1706
Heavy gas oil (800-1050)	0.1900	0.2214	0.1932	0.2059
Resid (1050+)	0.1701	0.2878	0.1827	0.2298
Total:	1.0001	0.9999	1.0003	1.0000
PROPERTIES (in ARMS)				
Sulfur (wt%)				
Kerosene (375-500)	0.16%	0.32%	0.34%	0.26%
Distillate (500-620)	0.32%	0.68%	0.86%	0.56%
Light Gas Oils (620-800)	0.96%	1.03%	1.31%	1.04%
Heavy Gas Oils (800-1050)	1.49%	1.65%	1.90%	1.63%
Resid (1050+)	2.49%	3.05%	3.79%	2.97%
API Gravity	31.6	23.4	30.3	27.3
Sulfur (wt %)	1.03%	1.64%	1.58%	1.41%
PROPERTIES (from Assays)				
API Gravity	29.5	18.3	29.3	23.8
Sulfur (wt %)	1.07%	1.81%	1.58%	1.51%

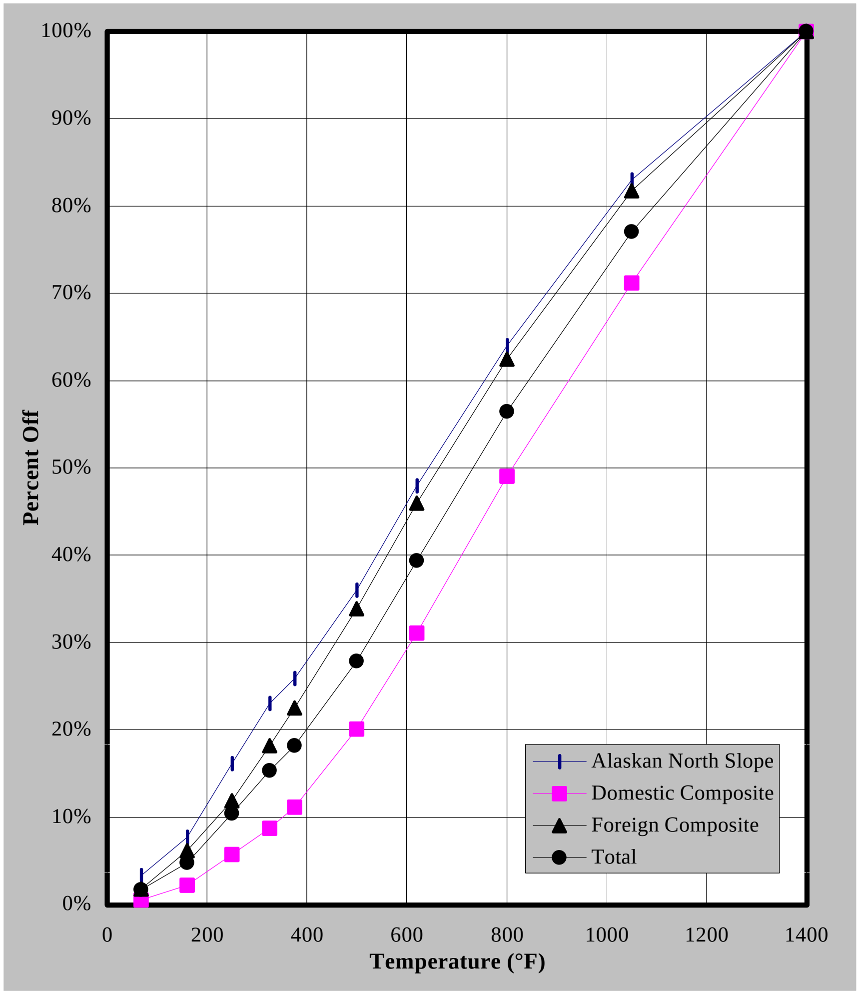

Exhibit 3: California Refinery Net Inputs -- Surveys and Calibration

Summer 1997

Input	Volume (K bbl/d)		Price ($/bbl)*	
	Surveys	Calibration	Spot	Calibration
Crude Oil	**1,757**	**1,725**		
Alaskan	657	645	18.03	19.15
Domestic Composite	866	850		18.61
Foreign Composite	234	230		19.12
Natural Gas Plant Liquids	**17**	**-**		
Liquified Petroleum Gases	16	-		
Normal Butane	4	-		14.56
Isobutane	12	0	22.19	18.84
Pentanes Plus	0	-		
Oxygenates	**104**	**104**		
Fuel Ethanol	nr	-		
Methanol	nr	5	28.56	28.56
MTBE	100	99	38.64	38.64
TAME**	4	-		37.69
Unfinished Oils	**53**	**50**		
Naphthas and Lighter	nr	-		
Kerosene and Light Gas Oils	nr	-		
Heavy Gas Oils	nr	17		19.56
Residuum	nr	33		14.91
Blending Components	**25**	**10**		
Propylene Alkylate	nr	5		28.02
Mixed Butylene Alkylate	nr	5		25.76
Others	nr	-		
Other Hydrocarbons & Hydrogen	**27**	**-**		
Purchased Energy				
Electricity (MM Kwh; $/Kwh)	**-**	14	0.06	0.06
Natural Gas (foeb)	**-**	184	18.50	18.50

* Spot -- Los Angeles refinery gate; Calibration -- ARMS shadow price.
** TAME shadow value is for captive TAME production with 50 ppm sulfur.
nr -- not reported.
Sources: Surveys -- PIIRA Data & 1998 California Refinery Survey; and
Calibration -- ARMS Calibration Results.

Exhibit 4: California Refinery Product Slate -- Surveys and Calibration

Summer 1997

Output	Volume (K bbl/d)		Price ($/bbl)*	
	Surveys	Calibration	Spot	Calibration
Liquified Refinery Gases	**67**	**65**		
Propane	33	33	14.37	10.78
Propylene	2	2		18.85
Butane	27	27		14.56
Isobutane	1	-	22.19	18.84
Mixed Butylenes	4	3		18.00
Special Naphthas	**1**	-		-
Motor Gasoline (1)	**1,087**	**1,087**		
California RFG	899	899	27.21	25.48
Premium	188	225	28.55	
Mid-grade	80	-		
Regular	631	674	26.76	
Arizona RFG	56	56		24.68
Premium	14	14		
Regular	42	42		
Conventional	132	132	26.10	22.49
Premium	26	26	28.44	
Regular	106	106	25.51	
Aviation Gasoline	**5**	**5**		26.07
Kerosene Jet Fuel (1) (2)	**296**	**296**	24.11	22.41
Distillate Fuel Oil (1)	**292**	**293**		
CARB Diesel	174	174	25.59	23.77
EPA Diesel	103	104	22.97	22.93
Other	15	15		22.60
Residual Fuel Oil (3)	**85**	**51**		
Under 0.31% sulfur	3	-		
0.31% to 1.00% sulfur	23	-		
Over 1.00% sulfur	60	-	14.59	
Petrochemical Feedstocks	**9**	**3**		
Naphtha < 401 °F	2	3		19.61
Other Oils > = 401 °F	7	-		
Lubricants	**19**	**22**		
Wax	**3**	-		
Asphalt and Road Oil	**7**	-		
Petroleum Coke (Marketable)	**111**	**123**		
Miscellaneous Products	**6**	-		
Sulfur (tons/d)	-	**5**		
Total (4)	**1,987**	**1,945**		

* Spot -- Los Angeles refinery gate; Calibration -- ARMS shadow price.
(1) Volume based on 1998 California Refinery Survey.
(2) Includes a small volume of naphtha jet fuel and kerosene (< 300 bbl/d combined).
(3) Calibration volume is the sum of various "produced" residual oil blendstocks -- coker bottoms, solvent deasphalting tar, kerosene, and light cycle oil.
(4) Excludes sulfur.
Sources: Surveys -- PIIRA Data & 1998 California Refinery Survey; and
Calibration -- ARMS Calibration results.

Exhibit 5.1: Volume and Properties of Gasoline Produced by California Refineries, by Grade and Class, CEC Survey -- Summer 1997

Measure		California RFG				Arizona RFG			Conventional			Total
		Premium	Mid-Grade	Regular	Pool*	Premium	Regular	Pool*	Premium	Regular	Pool*	Pool*
Volume	K bbl/day	188	80	631	899	14	42	56	26	106	132	1,086
Octane	MON (M)	87.6	*85.3*	83.4	84.4	87.2	83.0	84.0	87.3	82.3	83.2	84.3
	RON (R)	96.7	*93.8*	91.2	92.6	96.7	92.1	93.2	97.2	92.9	93.7	92.8
	CON (R+M)/2	92.2	*89.5*	87.3	88.5	92.0	87.5	88.6	92.2	87.6	88.5	88.5
Property	RVP (psi)	6.8	6.8	6.8	6.8	6.7	6.7	6.7	7.9	7.7	7.7	6.9
	Oxygen (wt%)	2.1	1.7	2.1	2.1	1.9	1.9	1.9	0.6	0.2	0.3	1.8
	Aromatics (vol%)	22.2	24.5	23.1	23.0	29.8	27.9	28.4	37.2	33.7	34.4	24.7
	Benzene (vol%)	0.43	0.46	0.62	0.57	0.64	0.64	0.64	0.67	0.74	0.73	0.59
	Olefins (vol%)	4.2	2.1	4.3	4.1	2.7	6.6	5.6	6.5	13.8	12.4	5.2
	Sulfur (ppm)	18	16	19	19	18	45	38	105	165	153	36
	E200 (%)	47.7	50.7	51.3	50.5	39.6	43.6	42.6	32.2	40.5	38.9	48.7
	E300 (%)	89.8	88.7	87.9	88.4	82.4	83.8	83.5	76.7	76.4	76.4	86.7
	API Gravity	60.0	58.4	58.6	58.9	55.8	54.9	55.1	53.2	54.9	54.6	58.2
	Butane (vol%)	0.9	1.1	0.4	0.5	1.3	0.4	0.6	4.6	1.8	2.3	0.8
	Pentane (vol%)	9.2	13.4	11.5	11.2	7.2	4.4	5.1	5.2	6.5	6.3	10.3
Distillation (°F)	IBP	97	97	98	97	97	97	97	90	89	89	89
	T10	139	137	138	138	143	140	140	137	131	132	137
	T30	174	165	165	167	188	174	177	194	176	179	169
	T50	205	198	196	198	222	218	219	239	224	227	203
	T70	248	248	244	245	260	273	269	286	283	283	251
	T90	301	301	304	303	338	337	337	339	341	341	309
	FBP	384	383	376	384	411	410	411	420	417	420	420
Oxygenate Distribution (vol%)	MTBE	96.0	92.6	96.1	95.8	100.0	100.0	100.0	97.0	97.6	97.5	96.2
	TAME	4.0	7.4	3.9	4.2	0.0	0.0	0.0	3.1	2.4	2.5	3.8
	Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Note: Mid-grade CARB gasoline octanes revised due to reporting error.

* Volume weighted average, except for distillation IBP & FBP (which are minumum and maximums, respectively)..

Source: 1998 California Refinery Survey.

Exhibit 5.2: Volume and Properties of Gasoline Produced by California Refineries, by Grade and Class, API/NPRA Survey -- Summer 1996

Measure		California RFG				Conventional			Total
		Premium	Mid-Grade	Regular	Pool	Premium	Regular	Pool	Pool
Volume	K bbl/day	139	55	541	736	28	124	152	888
Octane	CON (R+M)/2	92.2	89.5	87.8	88.8	92.2	87.8	88.6	88.7
Property	RVP (psi)	6.8	6.8	6.8	6.8	7.1	7.6	7.5	6.9
	Oxygen (wt%)	2.2	2.1	2.0	2.1	0.7	0.1	0.2	1.8
	Aromatics (vol%)	22.8	23.5	23.0	23.0	36.2	32.9	33.5	24.8
	Benzene (vol%)	0.38	0.49	0.60	0.6	0.68	0.75	0.7	0.6
	Olefins (vol%)	3.6	3.5	4.0	3.9	5.3	13.4	11.9	5.3
	Sulfur (ppm)	18	20	20	19.6	57	132	118.3	36.5
	E200 (%)	48.4	52.6	51.9	51.3	32.4	39.5	38.2	49.0
	E300 (%)	88.8	90.1	88.6	88.8	78.2	75.4	75.9	86.6
	API Gravity	59.7	59.4	59.1	59.2	54.1	54.9	54.8	58.5
Distillation (°F)	T10	138	138	138	138	138	133	134	137
	T50	205	196	195	197	237	228	230	203
	T90	300	300	303	302	332	344	342	309

Note: API/NPRA Survey included 10 refineries.
Source: API/NPRA 1996 Survey.

Exhibit 5.3: Volume and Properties of Gasoline -- Surveys and Calibration

Measure		California RFG			Arizona RFG		Conventional		Total Pool		
		CEC	API/NPRA	Calibration	CEC	Calibration	CEC	Calibration	CEC	API/NPRA	Calibration
Volume	K bbl/day	899	736	899	56	56	132	132	1,086	888	1,087
Octane	CON (R+M)/2	88.5	88.8	88.8	88.6	88.6	88.5	88.5	88.5	88.7	88.7
Property	RVP (psi)	6.8	6.8	6.8	6.7	6.7	7.7	7.7	6.9	6.9	6.9
	Oxygen (wt%)	2.1	2.1	2.1	1.9	2.1	0.3	0.3	1.8	1.8	1.9
	Aromatics (vol%)	23.0	23.0	22.9	28.4	28.4	34.4	34.4	24.7	24.8	24.6
	Benzene (vol%)	0.57	0.55	0.55	0.64	0.80	0.73	0.80	0.59	0.58	0.59
	Olefins (vol%)	4.1	3.9	4.3	5.6	5.6	12.4	12.4	5.2	5.3	5.3
	Sulfur (ppm)	18.6	19.6	18.8	37.9	38.0	153.0	153.0	35.8	36.5	36.1
	E200 (%)	50.5	51.3	50.5	42.6	42.6	38.9	38.9	48.7	49.0	48.7
	E300 (%)	88.4	88.8	89.1	83.5	83.5	76.4	76.4	86.7	86.6	87.2
	Energy Density			5.129		5.164		5.257			5.146
Distillation (°F)*	T10	138	138	135	140	135	132	139	137	137	135
	T30	167		167	177	172	179	187	169		170
	T50	198	197	199	219	219	227	227	203	203	204
	T70	245		248	269	264	283	279	251		252
	T90	303	302	303	337	327	341	347	309	309	310
Distillation (% Off)	100°			1.5		1.0		3.4			1.7
	130°			7.7		7.4		7.1			7.6
	175°			35.2		32.2		21.7			33.4
	200°			50.5		42.6		38.9			48.7
	212°			55.4		47.2		43.9			53.6
	257°			73.7		67.4		62.3			72.0
	280°			82.1		76.5		70.4			80.4
	300°			89.1		83.5		76.4			87.2
	356°			97.7		97.4		91.9			97.0
Pred. Model -- % Emissions	Hydrocarbons	-0.61	-0.85	-0.52							
	NOx	-0.49	-0.53	-0.41							
	Pot. Wt. Toxics	-0.73	-1.63	-0.73							

* Distillation temperatures for the Calibration are interpolated from ARMS-generated distillation curves (in terms of % off at various temperatures).

Sources: Exhibits 5.1 & 5.2 and ARMS Calibration Results.

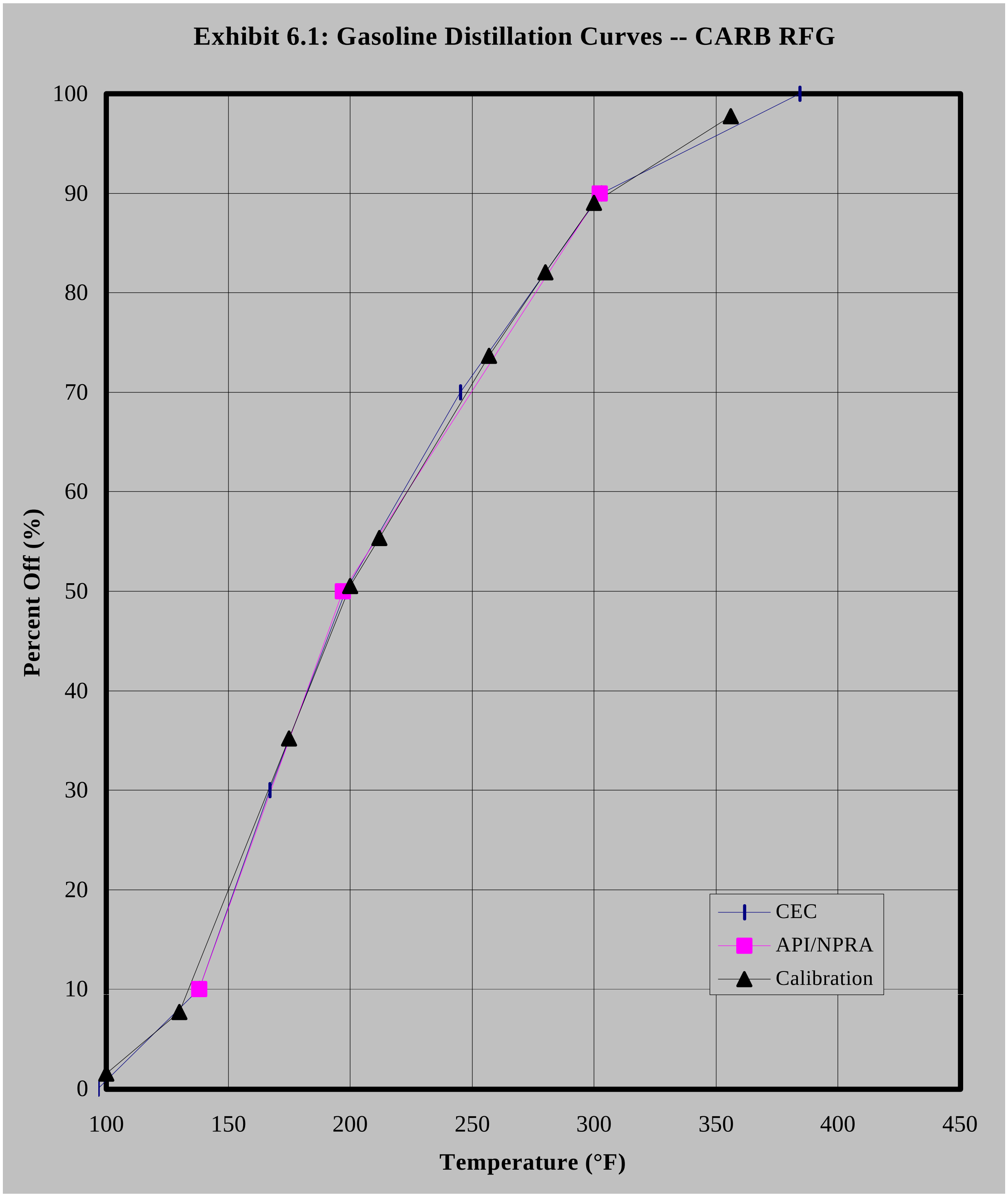

Exhibit 6.1: Gasoline Distillation Curves -- CARB RFG
Percent Off (%)
0
10
20
30
40
50
60
70
80
90
100
100
150
200
250
300
350
400
450
Temperature (°F)
CEC
API/NPRA
Calibration

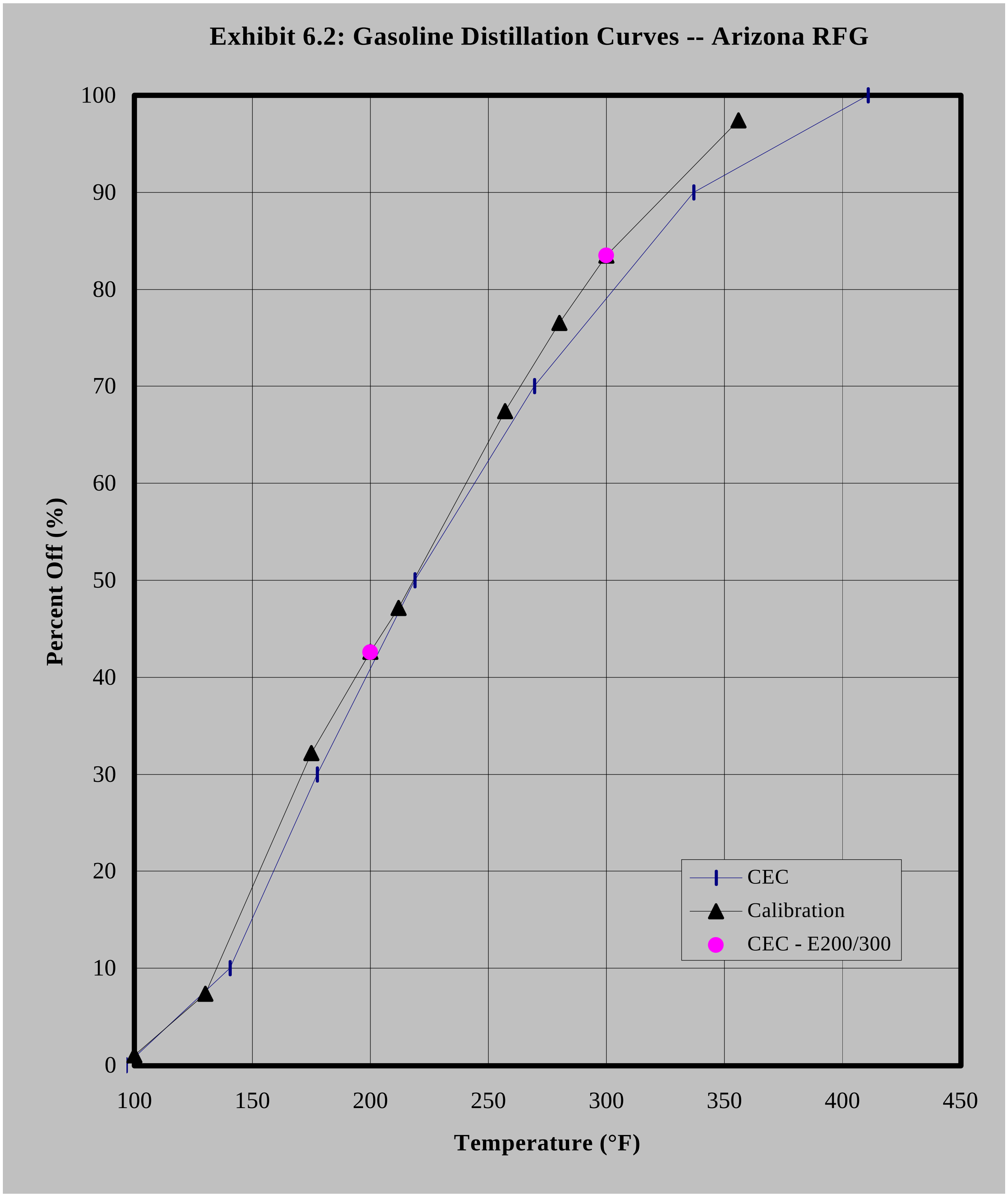

Exhibit 6.2: Gasoline Distillation Curves -- Arizona RFG
Percent Off (%)
0
10
20
30
40
50
60
70
80
90
100
100
150
200
250
300
350
400
450
Temperature (°F)
CEC
Calibration
CEC - E200/300

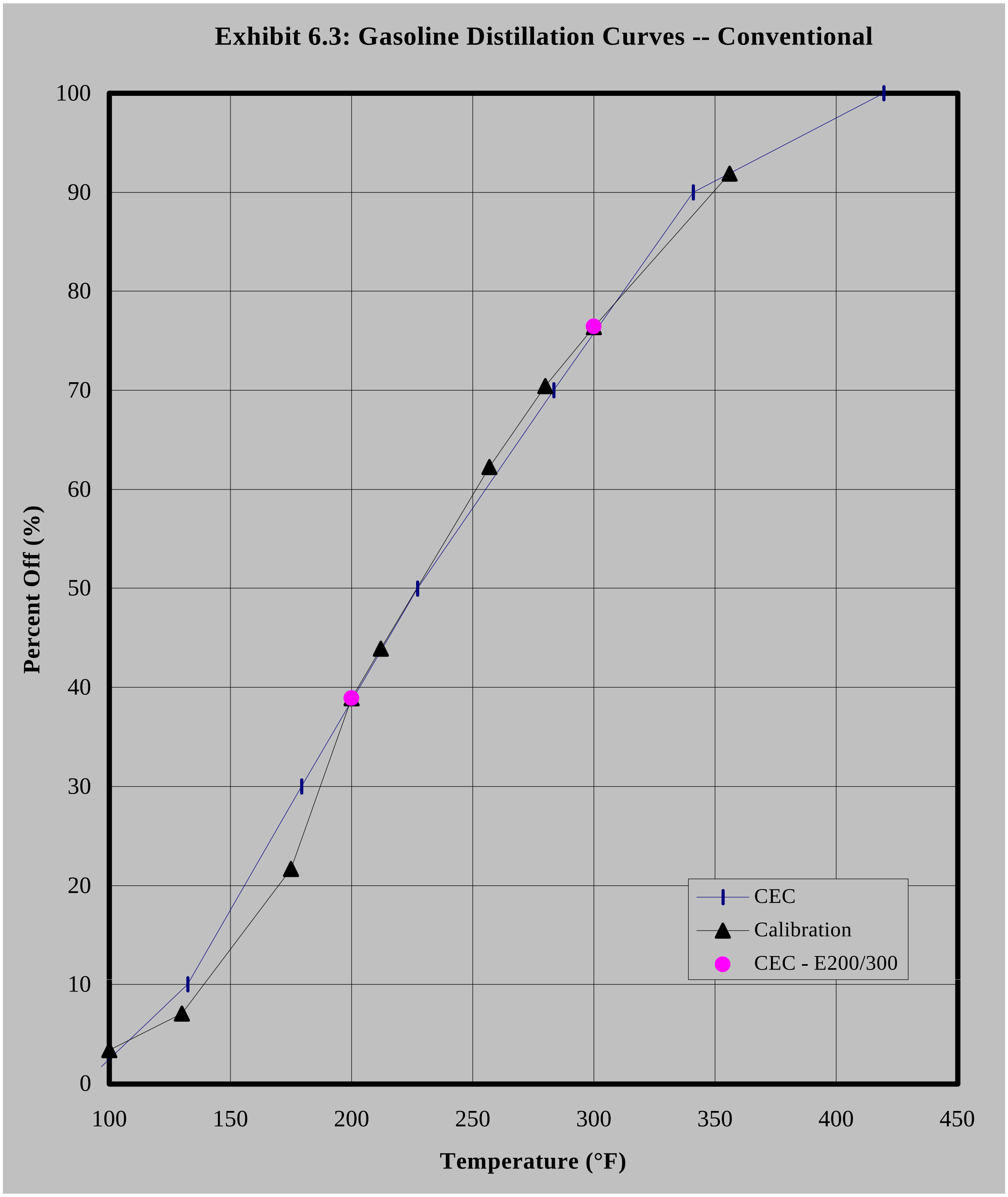
Exhibit 6.3: Gasoline Distillation Curves -- Conventional
Percent Off (%)
Temperature (°F)
0
10
20
30
40
50
60
70
80
90
100
100
150
200
250
300
350
400
450
CEC
Calibration
CEC - E200/300

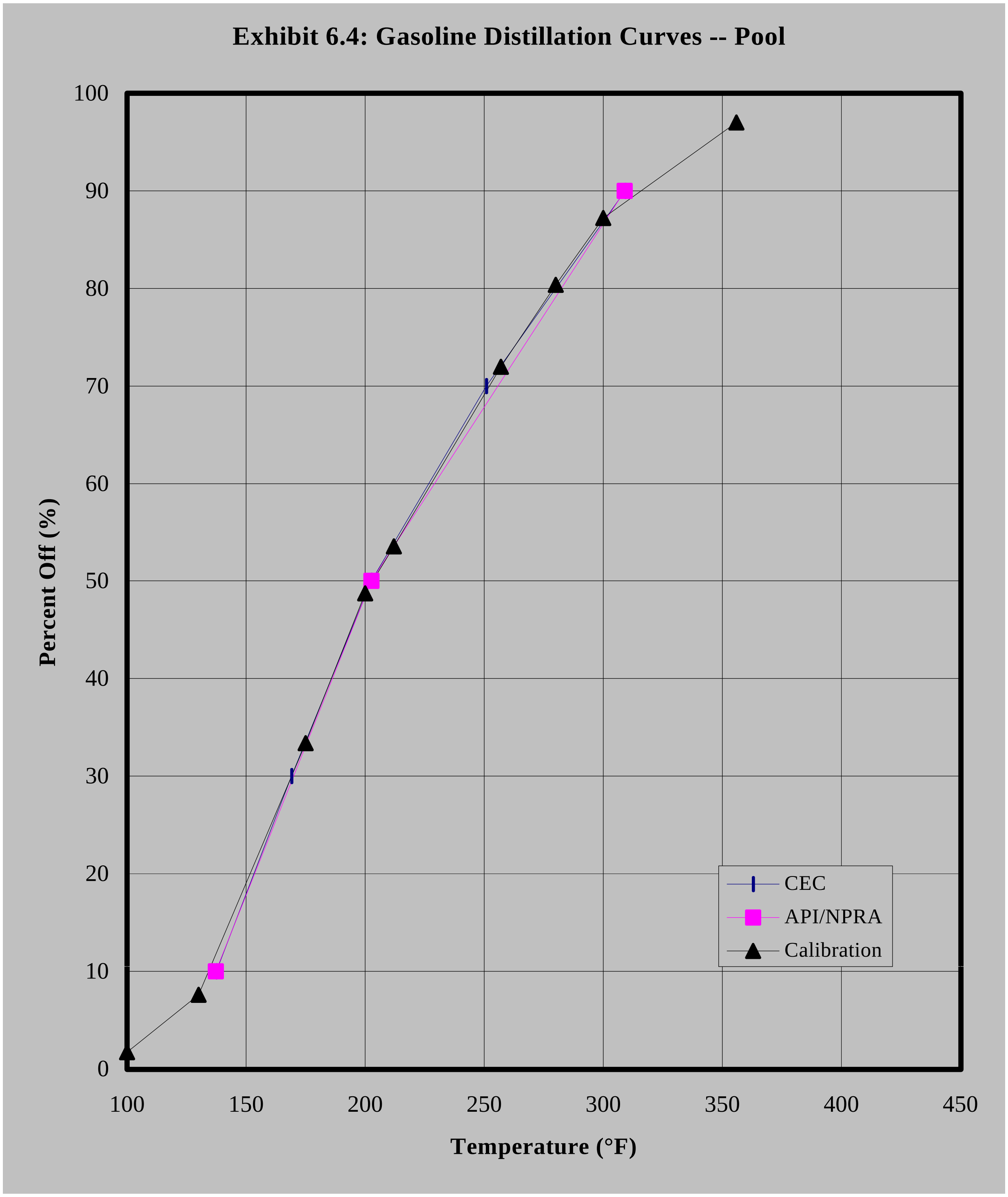

Exhibit 6.4: Gasoline Distillation Curves -- Pool
Percent Off (%)
Temperature (°F)
0
10
20
30
40
50
60
70
80
90
100
100
150
200
250
300
350
400
450
CEC
API/NPRA
Calibration

Exhibit 7: Gasoline Composition -- Calibration

Blendstock	Volume (K bbl/d)			Composition (vol %)		
	CARB RFG	Arizona RFG	Conv. Gasoline	CARB RFG	Arizona RFG	Conv. Gasoline
C4s:	5.9	0.3	5.0	0.7	0.5	3.8
Butenes						
I-Butane						
N-Butane	5.9	0.3	5.0	0.7	0.5	3.8
C5s & Isomerate	46.0	0.9	14.2	5.1	1.6	10.7
Raffinate						
Natural Gas Liquids						
Naphtha:	17.3	3.6	7.6	1.9	6.5	5.8
C5-160	17.3	3.6	7.6	1.9	6.5	5.8
Coker Naphtha						
160-250						
Alkylate:	142.1	5.9	2.2	15.8	10.6	1.6
C3	81.2	0.8	2.2	9.0	1.4	1.6
C4	60.9	5.2	0.0	6.8	9.2	0.0
Hydrocrackate:	162.1	5.4	0.0	18.0	9.6	
Light	76.7			8.5		
Medium	85.4	5.4		9.5	9.6	
Heavy						
FCC Gasoline:	233.4	18.1	71.6	26.0	32.3	54.2
Full Range	174.4		23.4	19.4		17.7
Light	22.0	6.4		2.4	11.3	
Medium	6.6	3.9	26.6	0.7	7.0	20.2
Medium - Desulf	30.4	1.7		3.4	3.0	
Heavy						
Heavy - Desulf		6.2	21.6		11.0	16.4
Reformate:	188.2	15.3	29.2	20.9	27.3	22.2
Light	66.2	8.0	29.2	7.4	14.3	22.2
Heavy	122.0	7.3	0.0	13.6	13.0	
Oxygenate	104.0	6.5	2.2	11.6	11.5	1.6
Total	899.0	56.0	132.0	100.0	100.0	100.0

Source: ARMS Calibration results.

Exhibit 8: Jet Fuel and Diesel Fuel Properties -- Surveys and Calibration

Property	Jet Fuel			CARB Diesel Fuel			EPA Diesel Fuel			Other Distillate		
	CEC	API/NPRA	Calib.	CEC	API/NPRA	Calib.	CEC	API/NPRA	Calib.	CEC	API/NPRA	Calib.
Volume (K bbl/d)	296	215	296	174	130	174	103	70	104	15	9	15
Property												
API Gravity	40.9	41.2	41.3	36.8	36.5	36.2	32.6	33.6	34.7	-	30.8	33.0
Aromatics (vol%)	19.0	18.9	19.0	15.8	18.2	17.0	28.4	28.8	27.9	-	24.0	33.6
Sulfur (ppm)	415	584	501	141	140	142	227	200	235	-	322	3255.7
Cetane No. (clear)				48.8	50.1	49.0	40.6	42.6	41.0	-	44.4	40.0
Distillation (°F)												
IBP	322			351			380					
T10	353	353		430	440	438	446	447	438		498	455
T30	385		386				477		482			
T50	411	411	413	517	531	524	526	525	527		556	551
T70	438		439				560		571			
T90	486	484	-	615	623	614	612	612	614		620	621
FBP	527			664			657					

Note: Distillation temperatures for Calibration are estimated from ARMS-generated distillation curves.
API/NPRA Survey included 10 refineries.
Sources: 1998 California Refinery Survey; 1996 API/NPRA Survey; and ARMS Calibration Results.

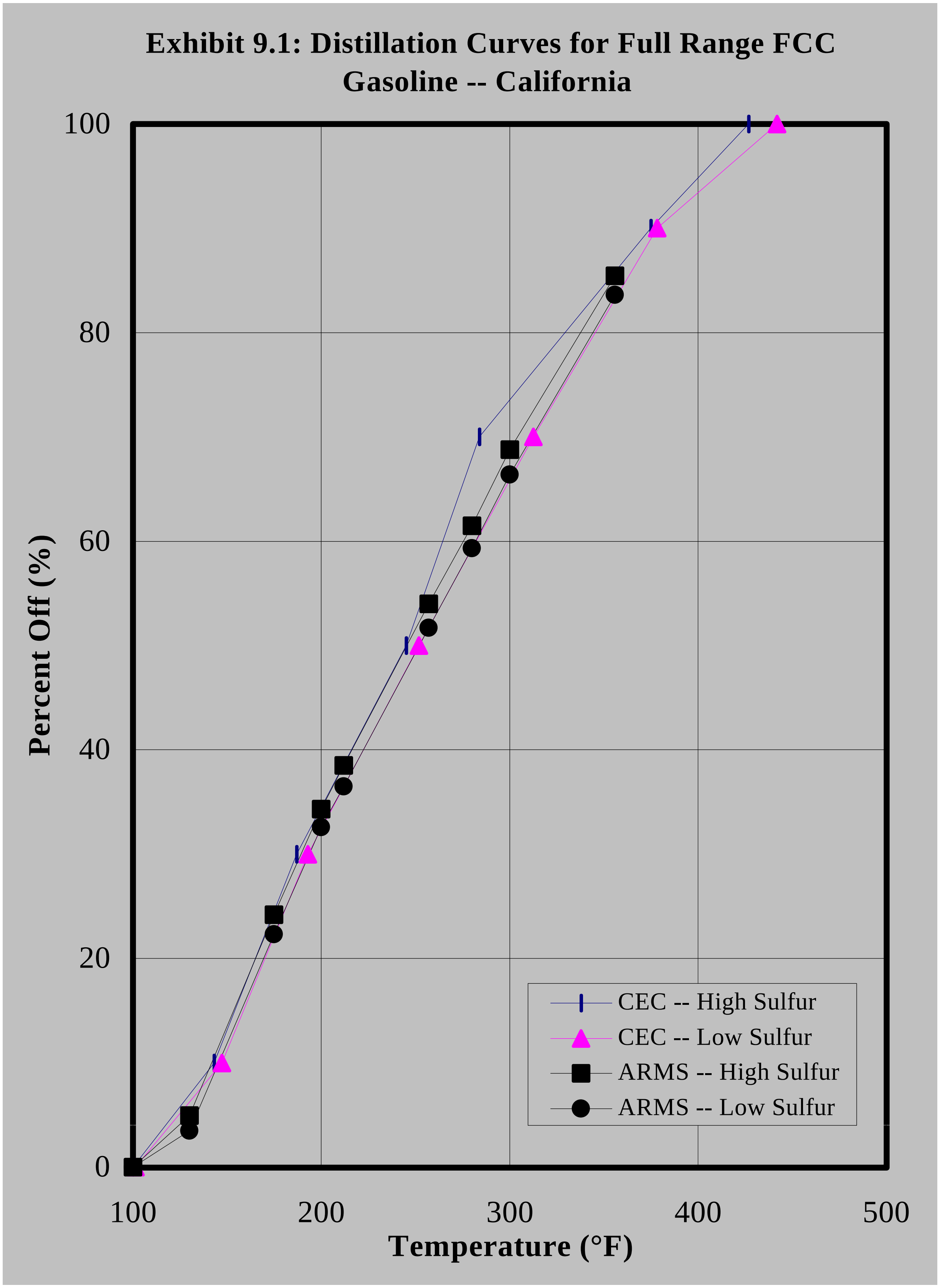
Exhibit 9.1: Distillation Curves for Full Range FCC Gasoline -- California
100
80
60
40
20
0
Percent Off (%)
100
200
300
400
500
Temperature (°F)
CEC -- High Sulfur
CEC -- Low Sulfur
ARMS -- High Sulfur
ARMS -- Low Sulfur

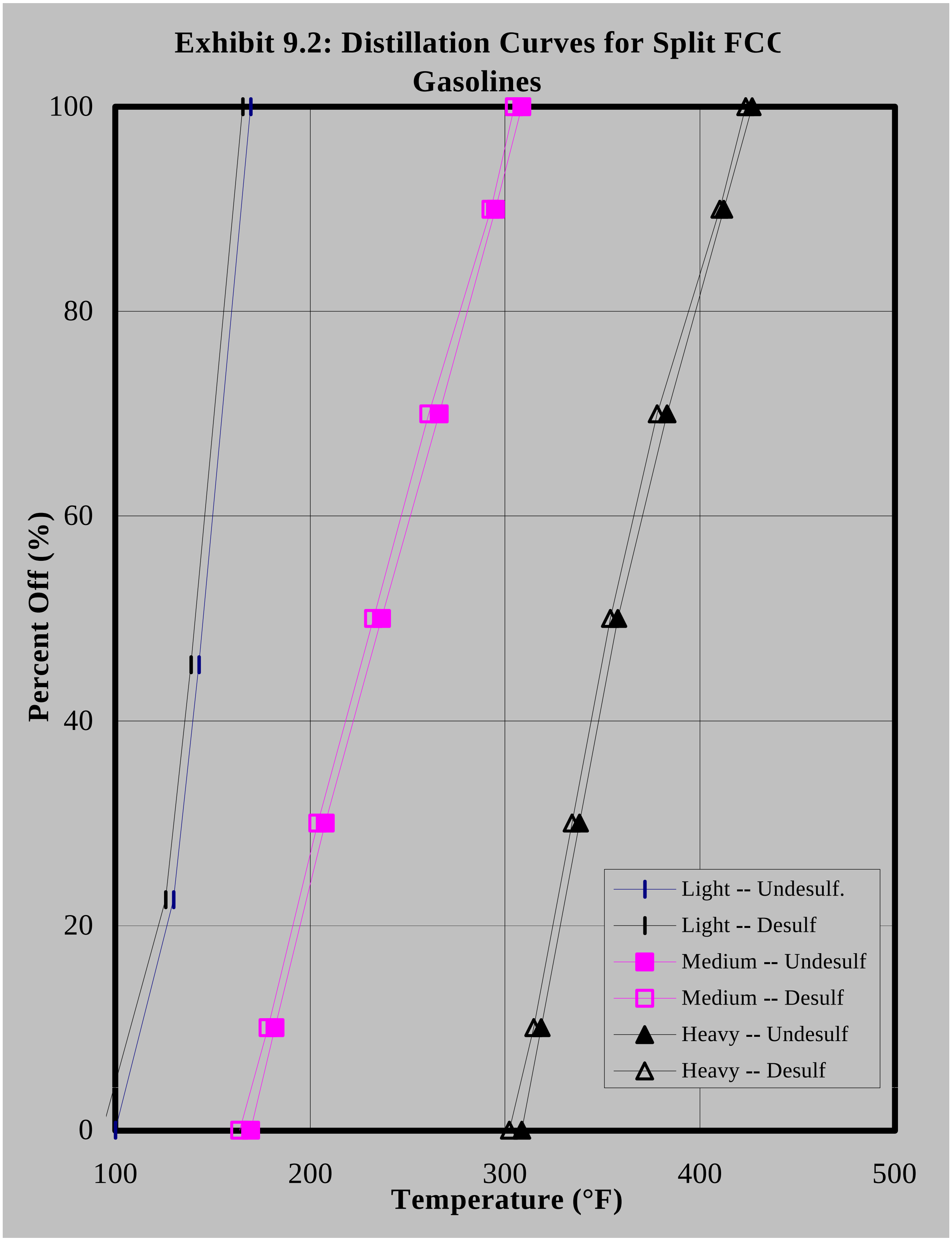
Exhibit 9.2: Distillation Curves for Split FCC
Gasolines
100
80
60
40
20
0
100
200
300
400
500
Percent Off (%)
Temperature (°F)
Light -- Undesulf.
Light -- Desulf
Medium -- Undesulf
Medium -- Desulf
Heavy -- Undesulf
Heavy -- Desulf

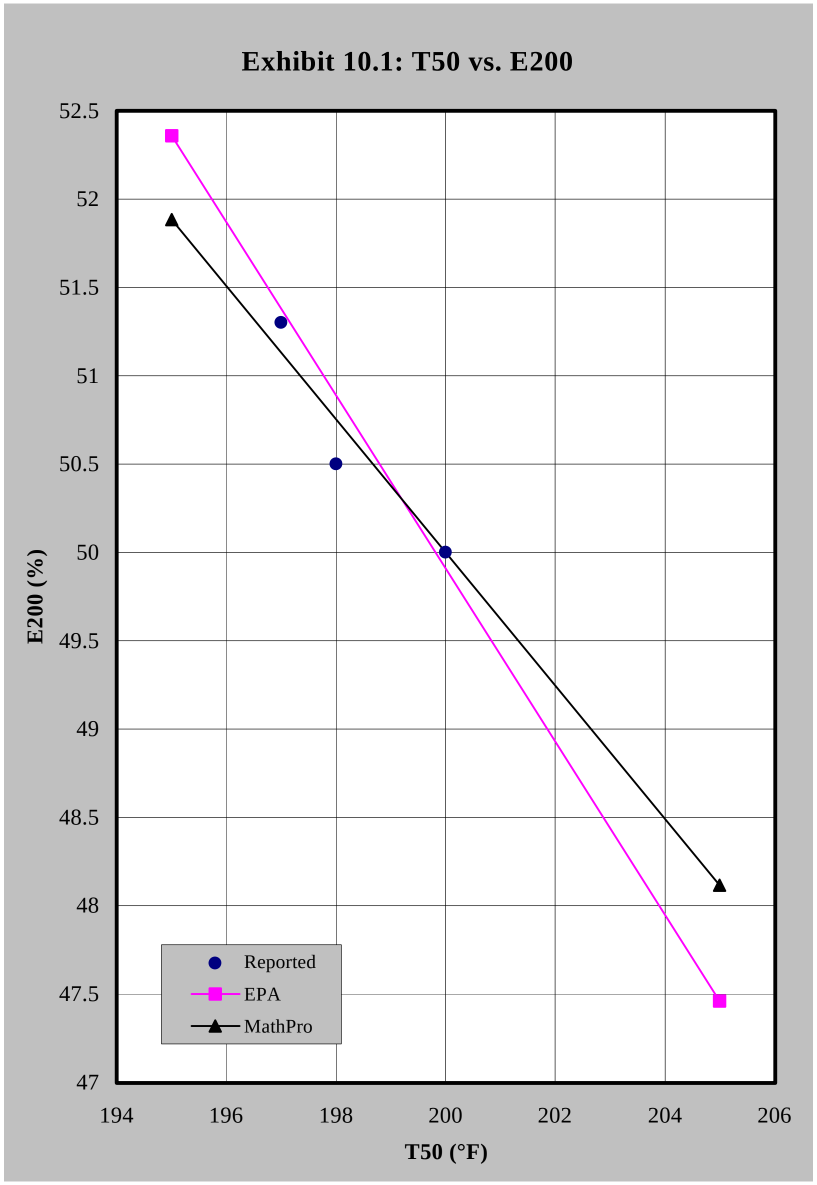
Exhibit 10.1: T50 vs. E200
E200 (%)
T50 (°F)
52.5
52
51.5
51
50.5
50
49.5
49
48.5
48
47.5
47
194
196
198
200
202
204
206
Reported
EPA
MathPro

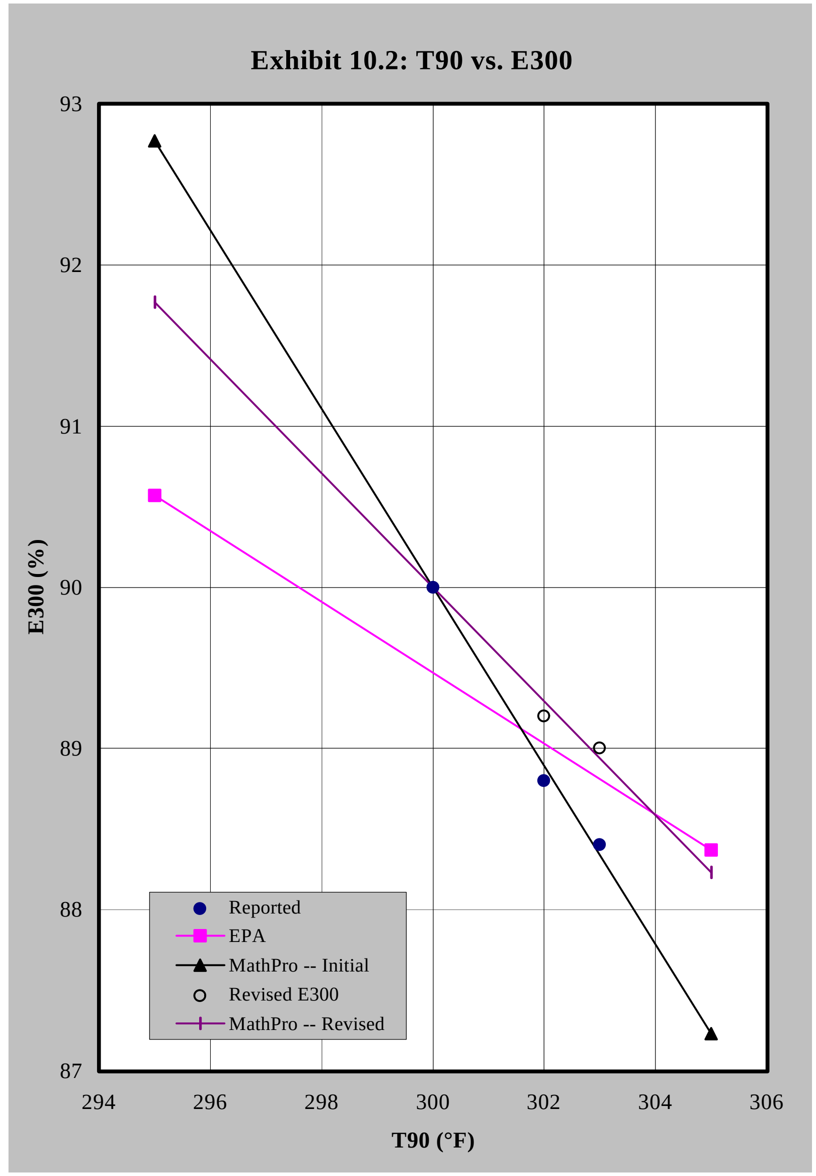
Exhibit 10.2: T90 vs. E300
E300 (%)
T90 (°F)
93
92
91
90
89
88
87
294
296
298
300
302
304
306
Reported
EPA
MathPro -- Initial
Revised E300
MathPro -- Revised

Exhibit 11: Summary of Gasoline Blending and Blendstock Properties

ARMS		Gasoline Type (K bbl/d)				Distillation (% Off)									RVP	OXY	ARO	BNZ	OLE	SUL	En.Den.	Octane	
Code	Description	CARB	AZ	Conv.	Pool	100°	130°	175°	200°	212°	257°	280°	300°	356°	(psi)	(wt%)	(vol%)	(vol%)	(vol%)	ppm	(MM btu/b)	MON	RON
IC4	Isobutane					30	80	100	100	100	100	100	100	100	71	0	0	0	0	4	4.197	97.4	100.8
NC4	Normal butane	5.9	0.3	5.0	11.2	30	80	100	100	100	100	100	100	100	65	0	0	0	2.6	4	4.364	91	94
UC4	Butylenes - mixed Co-mingled					30	80	100	100	100	100	100	100	100	68	0	0	0	100	4	4.449	81.7	101.2
JC4	Isobutylene					30	80	100	100	100	100	100	100	100	68	0	0	0	100	4	4.357	83.4	105.9
OC4	Normal butylene					30	80	100	100	100	100	100	100	100	68	0	0	0	100	4	4.521	81.5	98.8
OC5	Normal amylenes	0.5	0.9		1.4	10	30	70	100	100	100	100	100	100	16	0	0	0	66.6	5	4.8	75.5	90
IC5	Isopentane (once thru)					10	30	70	100	100	100	100	100	100	20.4	0	0	0	0	1	4.53	86.6	88.9
IC6	C6 Isomerate (once thru)					0	10	50	100	100	100	100	100	100	7.5	0	0.4	0.4	0	1	4.889	75	77
IC6T	C6 Isomerate (tot recycle)	15.8			15.8	0	10	50	100	100	100	100	100	100	7.5	0	0.4	0.4	0	1	4.889	80.2	82.3
ISOP	Isomerate (C5&C6 - once thru)					5	15	60	100	100	100	100	100	100	13.3	0	0.2	0.2	0	1	4.728	80.2	82.3
ISOT	Isomerate (C5&C6 - total recycle)	27.4		14.2	41.6	20	30	60	100	100	100	100	100	100	14.3	0	0.2	0.2	0	1	4.793	85.4	88.5
AROH	Aromatics Plant Overhead & from BXT					0	12	65	100	100	100	100	100	100	18	0	0.2	0.2	0	4	4.772	60	68
R5E	Reactive amylenes - from HCD					10	22	65	100	100	100	100	100	100	18	0	0	0	55	5	4.642	81.5	90.5
R5P	C5 Paraffins from DC5	2.3			2.3	10	23	70	100	100	100	100	100	100	20.5	0	0	0	0	5	4.566	83.4	85.1
NAT	Natural gasoline (NGL)					1	15	78	86	92	100	100	100	100	12.6	0	2.6	0	0.8	150	4.53	71	73
SRL	LSR naphtha (C5-160) Lo octane, 100 sul					0	6	60	100	100	100	100	100	100	13	0	0.1	0.1	0.4	100	4.825	59.9	59.2
SRI	LSR naphtha (C5-160) Me octane, 120 sul					0	6	60	100	100	100	100	100	100	13	0	0.1	0.1	0.4	120	4.928	70.7	70
SRH	LSR naphtha (C5-160) Hi octane, 150 sul			7.0	7.0	0	6	60	100	100	100	100	100	100	13	0	0.1	0.1	0.4	150	4.986	81.5	80.8
SRLA	LSR naphtha (C5-160) Lo octane,DeSul 15S					0	6	60	100	100	100	100	100	100	13	0	0.1	0.1	0.2	15	4.825	58.9	56.7
SRIA	LSR naphtha (C5-160) Me octane,DeSul 18S					0	6	60	100	100	100	100	100	100	13	0	0.1	0.1	0.2	18	4.928	69.7	67.5
SRHA	LSR naphtha (C5-160) Hi octane,DeSul 23S	17.3	3.6	0.6	21.5	0	6	60	100	100	100	100	100	100	13	0	0.1	0.1	0.2	23	4.986	80.5	78.3
CNL	Light coker naphtha (C5-160)					0	0	90	100	100	100	100	100	100	13	0	3	3	55.6	3600	4.978	74.5	82
TLN	Lt naphtha (C5-175)					0	0	90	100	100	100	100	100	100	9	0	21.6	21.6	1.2	10	4.956	75	77
LNP	Light naphtha (160-250) Par, 150 sul					0	0	1	40	50	95	100	100	100	2.5	0	6.4	2.8	3	150	5.122	42	41.3
LNI	Light naphtha (160-250) Int, 300 sul					0	0	1	40	50	95	100	100	100	2.5	0	7.8	3.6	3	300	5.179	55.5	55.9
LNN	Light naphtha (160-250) Nap, 400 sul					0	0	1	40	50	95	100	100	100	2.5	0	9.2	4.3	3	400	5.21	69.7	70.5
LNPA	Light naphtha (160-250) Par, DeSul 23S					0	0	1	40	50	95	100	100	100	2.5	0	6.4	2.8	1.5	23	5.122	41	38.8
LNIA	Light naphtha (160-250) Int, DeSul 45S					0	0	1	40	50	95	100	100	100	2.5	0	7.8	3.6	1.5	45	5.179	54.5	53.4
LNNA	Light naphtha (160-250) Nap, DeSul 60S					0	0	1	40	50	95	100	100	100	2.5	0	9.2	4.3	1.5	60	5.21	68.7	68
DMO	Dimerate					0	0	63	71	75	95	97	99	100	9	0	0	0	99	5	5.024	81	94.5
CPG	Polymer Gasoline					0	0	14	21	25	60	70	79	100	5.5	0	0.5	0	95	60	5.167	83	96
LHG	Light hydrocrackate (C5-160)	76.7			76.7	0	20	72	95	98	100	100	100	100	12.5	0	1	1	0.5	4	4.926	80.5	82
MHC	Hydrocracked gasoline (160-250) cracked	55.6			55.6	0	0	0	5	15	56	79	100	100	1.4	0	16	0.8	0.05	4	5.255	66	67
MHV	Hydrocracked gasoline (160-250) virgin	29.8	5.4		35.2	0	0	0	7	16	57	80	100	100	1.4	0	10	0.8	0.05	4	5.209	65	66
HHC	Hydrocracked gasoline (250-325) cracked					0	0	0	0	0	0	0	5	85	0.5	0	25	0	0	4	5.424	63	64
ALP	Propylene alkylate	81.2	0.8	2.2	84.2	0	4.5	31	76	83	94.6	97	98.4	100	3.8	0	0.4	0.4	0.1	12	5.123	89.5	91.5
ALB	Butylene alkylate	26.2			26.2	0	1.5	7	10.2	14	68	83	94	98	2.6	0	0.4	0.2	0.1	12	5.155	91.8	94.1
ALO	Normal butylene alkylate	34.8	5.2		39.9	0	1.5	7	10.2	14	68	83	94	98	2.6	0	0.4	0.2	0.1	12	5.188	93	95.3
ALC	Butylene alkylate, tailored, T90=280					0	1.5	7.8	11.3	15.6	75.6	92.2	100	100	2.8	0	0.2	0.2	0.1	12	5.139	91.8	94.1
ALE	Nor.butylene alkylate, tailored, T90=280					0	1.5	7.8	11.3	15.6	75.6	92.2	100	100	2.8	0	0.2	0.2	0.1	12	5.175	93	95.3
AL5	Iso and normal amylene alkylate					0	3.5	15	20	23	39	54	69	92	4	0	0.4	0.2	0.1	12	5.161	90.5	92
W90	Lt. Reformate (160-250)					0	0	18	37	46	80	94	100	100	7.5	0	56.5	8.75	0	2	5.304	83	90
W95	Lt. Reformate (160-250)					0	0	18	37	46	80	94	100	100	7.5	0	63.5	9.8	0	2	5.337	86.4	95
W10	Lt. Reformate (160-250)			2.9	2.9	0	0	18	37	46	80	94	100	100	7.5	0	71.5	11	0	2	5.372	90.9	100
W25	Lt. Reformate (160-250)					0	0	18	37	46	80	94	100	100	7.5	0	76.5	11.76	0	2	5.389	93.9	102.5
WS90	Lt. Ref (160-250) after BSA, W90 feed					0	0	18	37	46	80	94	100	100	7.5	0	47.9	0.1	0	2	5.276	81.3	88
WS95	Lt. Ref (160-250) after BSA, W95 feed					0	0	18	37	46	80	94	100	100	7.5	0	53.8	0.1	0	2	5.306	84.4	92.8
WS10	Lt. Ref (160-250) after BSA, W10 feed	36.3			36.3	0	0	18	37	46	80	94	100	100	7.5	0	60.6	0.1	0	2	5.337	88.8	97.5
WS25	Lt. Ref (160-250) after BSA, W25 feed					0	0	18	37	46	80	94	100	100	7.5	0	64.8	0.1	0	2	5.351	91.5	99.8

Exhibit 11: Summary of Gasoline Blending and Blendstock Properties

ARMS		Gasoline Type (K bbl/d)				Distillation (% Off)									RVP	OXY	ARO	BNZ	OLE	SUL	En.Den.	Octane	
Code	Description	CARB	AZ	Conv.	Pool	100°	130°	175°	200°	212°	257°	280°	300°	356°	(psi)	(wt%)	(vol%)	(vol%)	(vol%)	ppm	(MM btu/b)	MON	RON
V90	Lt. Ref (175-250),BNZ prec. remov,90R					0	0	7.6	24.5	35.2	76	92.8	100	100	5.6	0	56.5	0.8	0	2	5.331	83.3	90
V95	Lt. Ref (175-250),BNZ prec. remov,95R	4.5			4.5	0	0	7.6	24.5	35.2	76	92.8	100	100	5.6	0	63.5	0.9	0	2	5.365	86.7	95
V10	Lt. Ref (175-250),BNZ prec. remov,100R	25.3	8.0	26.4	59.7	0	0	7.6	24.5	35.2	76	92.8	100	100	5.6	0	71.5	1	0	2	5.4	91.2	100
V25	Lt. Ref (175-250),BNZ prec. remov,102.5R					0	0	7.6	24.5	35.2	76	92.8	100	100	5.6	0	76.5	1.1	0	2	5.418	94.2	102.5
M90	Med. Reformate (250-300)					0	0	3	10.8	16.4	40.5	56	70.5	100	4.9	0	56.5	1.82	0	2	5.426	80.5	90
M95	Med. Reformate (250-300)					0	0	3	10.8	16.4	40.5	56	70.5	100	4.9	0	63.5	2.03	0	2	5.462	83.2	95
M10	Med. Reformate (250-300)					0	0	3	10.8	16.4	40.5	56	70.5	100	4.9	0	71.5	2.29	0	2	5.499	87.7	100
M25	Med. Reformate (250-300)					0	0	3	10.8	16.4	40.5	56	70.5	100	4.9	0	76.5	2.44	0	2	5.517	90.7	102.5
MS95	Medium reformate after BSA--M95 feed					0	0	3	10.8	16.4	40.5	56	70.5	100	4.9	0	61.6	0.1	0	2	5.46	82.9	94.6
MS10	Medium reformate after BSA--M10 feed					0	0	3	10.8	16.4	40.5	56	70.5	100	4.9	0	69.3	0.1	0	2	5.497	87.3	99.5
R90	Hvy Reformate (250-325)					0	0	2.3	8	12	31	44	56.8	90	3.8	0	56.5	1.39	0	2	5.491	80	90
R95	Hvy Reformate (250-325)					0	0	2.3	8	12	31	44	56.8	90	3.8	0	63.5	1.56	0	2	5.529	82.6	95
R10	Hvy Reformate (250-325)	14.2	7.3		21.5	0	0	2.3	8	12	31	44	56.8	90	3.8	0	71.5	1.75	0	2	5.567	87.1	100
R25	Hvy Reformate (250-325)					0	0	2.3	8	12	31	44	56.8	90	3.8	0	76.5	1.87	0	2	5.586	90.1	102.5
RS95	Hvy. Ref (250-325) after BSA, R95 feed					0	0	2.3	8	12	31	44	56.8	90	3.8	0	62	0.1	0	2	5.528	82.4	94.7
RS10	Hvy. Ref (250-325) after BSA, R10 feed	107.9			107.9	0	0	2.3	8	12	31	44	56.8	90	3.8	0	69.8	0.1	0	2	5.566	86.7	99.6
RT90	Top end of R90					0	0	4.6	15.9	24	62	88	100	100	6.6	0	56.5	2.8	0	2	5.384	79	89
RT95	Top end of R95					0	0	4.6	15.9	24	62	88	100	100	6.6	0	63.5	3.1	0	2	5.419	81.6	94
RT10	Top end of R10					0	0	4.6	15.9	24	62	88	100	100	6.6	0	71.5	3.5	0	2	5.455	86.1	99
RT25	Top end of R25					0	0	4.6	15.9	24	62	88	100	100	6.6	0	76.5	3.8	0	2	5.472	89.1	101.5
RTS95	Top end of R95 after BSA					0	0	4.6	15.9	24	62	88	100	100	6.6	0	60.5	0.1	0	2	5.416	81	93.3
RTS10	Top end of R10 after BSA					0	0	4.6	15.9	24	62	88	100	100	6.6	0	68.1	0.1	0	2	5.452	85.4	98.2
MBE	MTBE (methyl tertiary butyl ether)	98.9			98.9	6	22	107	112	115	113	112	111	111	8	18.2	0	0	0.2	10	4.275	102	118
MBES	MTBE -- captive	3.4	6.5	2.2	12.0	6	22	107	112	115	113	112	111	111	8	18.2	0	0	0.2	50	4.275	102	118
TAM	TAME (tertiary amyl methyl ether)	1.7			1.7	0	0	104	105	105	105	104	103	100	2	15.7	0	0	0.2	50	4.551	95	115
FC6D	Full Range FCC gas, De Sulf., 60% conv.					0	5	24.2	34.3	38.5	54	61.5	68.8	85.4	6		24.8	0.67	30.6	400	5.332	79.9	91.3
FC7D	Full Range FCC gas, De Sulf., 70% conv					0	5	24.2	34.3	38.5	54	61.5	68.8	85.4	6		27	0.73	32.6	400	5.347	80.2	91.6
FC8D	Full Range FCC gas, De Sulf., 80% conv.					0	5	24.2	34.3	38.5	54	61.5	68.8	85.4	6		31.4	0.85	34.8	400	5.363	80.7	92.8
FC6E	Full Range FCC gas, DeepDeSulf,60% conv.					0	3.5	22.3	32.6	36.5	51.7	59.3	66.4	83.6	6		30.9	0.67	10.8	60	5.366	79.9	91.3
FC7E	Full Range FCC gas, DeepDeSulf,70% conv.	74.3			74.3	0	3.5	22.3	32.6	36.5	51.7	59.3	66.4	83.6	6		33.1	0.73	11.6	60	5.382	80.2	91.6
FC8E	Full Range FCC gas, DeepDeSulf,80% conv.					0	3.5	22.3	32.6	36.5	51.7	59.3	66.4	83.6	6		37.5	0.85	12.3	60	5.398	80.7	92.8
FC6ET	T90 Control (C5-375),DeepDeslf,60% conv.					0	3.9	25.1	36.6	41	58.1	66.7	74.6	94	6.8		25.9	0.75	12	46	5.313	80.6	92.2
FC7ET	T90 Control (C5-375),DeepDeslf,70% conv.	17.0			17.0	0	3.9	25.1	36.6	41	58.1	66.7	74.6	94	6.8		27.7	0.82	12.9	46	5.327	80.9	92.5
FC8ET	T90 Control (C5-375),DeepDeslf,80% conv.	83.1			83.1	0	3.9	25.1	36.6	41	58.1	66.7	74.6	94	6.8		31.3	0.95	13.7	46	5.344	81.4	93.7
FC6D-D	Depentanized FCC gas, De Sulf, 60% conv					0	0	16.2	27.3	32	49.1	57.4	65.5	83.9	4.3		27.4	0.74	28.2	433	5.408	79.7	91.4
FC7D-D	Depentanized FCC gas, De Sulf, 70% conv			23.4	23.4	0	0	16.2	27.3	32	49.1	57.4	65.5	83.9	4.3		29.8	0.81	30.2	433	5.424	80.1	91.8
FC8D-D	Depentanized FCC gas, De Sulf, 80% conv					0	0	16.2	27.3	32	49.1	57.4	65.5	83.9	4.3		34.7	0.74	32.6	433	5.442	80.6	93.1
LF6D	Light FCC gasoline, De Sulf., 60% conv.	3.5			3.5	0	23	100	100	100	100	100	100	100	20		1.6	1.6	58.2	41	4.988	81.2	93.5
LF7D	Light FCC gasoline, De Sulf., 70% conv.	14.3			14.3	0	23	100	100	100	100	100	100	100	20		1.7	1.7	62.2	41	4.999	81.5	93.8
LF8D	Light FCC gasoline, De Sulf., 80% conv.					0	23	100	100	100	100	100	100	100	20		2	2	66.3	41	5.011	82	95
LF6C	Light FCC gasoline, DeSulf-Convtnl,60%cv					0	30	100	100	100	100	100	100	100	20		1.5	1.5	14.6	10	4.978	73.2	85.5
LF7C	Light FCC gasoline, DeSulf-Convtnl,70%cv					0	30	100	100	100	100	100	100	100	20		1.6	1.6	15.6	10	5	73.5	85.8
LF8C	Light FCC gasoline, DeSulf-Convtnl,80%cv		6.2		6.2	0	30	100	100	100	100	100	100	100	20		1.7	1.9	16.6	10	5.012	74	87
LE6D	Lt.FCC gaso,deR5Ed, De Sulf., 60% conv.					0	0	100	100	100	100	100	100	100	17.8		2.8	2.8	60.6	61	5.272	80.9	95.8
LE7D	Lt.FCC gaso,deR5Ed, De Sulf., 70% conv.					0	0	100	100	100	100	100	100	100	17.8		3.1	3.1	67.6	61	5.291	81.4	96.3
LE8D	Lt.FCC gaso,deR5Ed, De Sulf., 80% conv.					0	0	100	100	100	100	100	100	100	17.8		3.6	3.6	74.8	61	5.312	82.3	98.5

Exhibit 11: Summary of Gasoline Blending and Blendstock Properties

ARMS		Gasoline Type (K bbl/d)				Distillation (% Off)									RVP	OXY	ARO	BNZ	OLE	SUL	En.Den.	Octane	
Code	Description	CARB	AZ	Conv.	Pool	100°	130°	175°	200°	212°	257°	280°	300°	356°	(psi)	(wt%)	(vol%)	(vol%)	(vol%)	ppm	(MM btu/b)	MON	RON
LE6C	Lt.FCC gaso,deR5Ed, DeSulf-Convtnl,60%cv					0	0	100	100	100	100	100	100	100	17.8		2.7	2.7	15.2	15	5.272	72.9	87.8
LE7C	Lt.FCC gaso,deR5Ed, DeSulf-Convtnl,70%cv		0.0		0.0	0	0	100	100	100	100	100	100	100	17.8		3	3	16.9	15	5.291	73.4	88.3
LE8C	Lt.FCC gaso,deR5Ed, DeSulf-Convtnl,80%cv	4.2	0.1		4.3	0	0	100	100	100	100	100	100	100	17.8		3.5	3.5	18.7	15	5.312	74.3	90.5
MF6D	MediumFCC gasoline, De Sulf., 60% conv.			7.6	7.6	0	0	4.4	24.6	33	64	79	93.6	100	3		19.6	0.6	32.1	267	5.295	79.2	90
MF7D	MediumFCC gasoline, De Sulf., 70% conv.	6.6	3.9	19.0	29.6	0	0	4.4	24.6	33	64	79	93.6	100	3		21.4	0.7	34.3	267	5.309	79.5	90.3
MF8D	MediumFCC gasoline, De Sulf., 80% conv.					0	0	4.4	24.6	33	64	79	93.6	100	3		24.8	0.8	36.5	267	5.325	80	91.5
MF6C	Medium FCC gasoline,DeSulf-Convtnl,60%cv					0	0	7.7	27	35.7	67.3	81.6	96	100	3		18.3	0.6	3.2	27	5.274	75.2	81.5
MF7C	Medium FCC gasoline,DeSulf-Convtnl,70%cv		1.7		1.7	0	0	7.7	27	35.7	67.3	81.6	96	100	3		20	0.7	3.4	27	5.288	75.5	81.8
MF8C	Medium FCC gasoline,DeSulf-Convtnl,80%cv	30.4			30.4	0	0	7.7	27	35.7	67.3	81.6	96	100	3		23.2	0.8	3.7	27	5.304	76	83
HF6D	Heavy FCC gasoline, De Sulf., 60% conv.					0	0	0	0	0	0	0	0	48	0.5		52.3	0	6.1	841	5.669	80.2	92
HF7D	Heavy FCC gasoline, De Sulf., 70% conv.					0	0	0	0	0	0	0	0	48	0.5		56.9	0	6.5	841	5.688	80.5	92.3
HF8D	Heavy FCC gasoline, De Sulf., 80% conv.					0	0	0	0	0	0	0	0	48	0.5		66.1	0	6.9	841	5.709	81	93.5
HF6C	Heavy FCC gasoline,DeSulf-Convtnl,60%cv			4.1	4.1	0	0	0	0	0	0	0	0	52	0.5		49.3	0.3	0.6	84	5.621	80.2	92
HF7C	Heavy FCC gasoline,DeSulf-Convtnl,70%cv			5.5	5.5	0	0	0	0	0	0	0	0	52	0.5		53.6	0.3	0.7	84	5.641	80.5	92.3
HF8C	Heavy FCC gasoline,DeSulf-Convtnl,80%cv					0	0	0	0	0	0	0	0	52	0.5		62.3	0.3	0.7	84	5.663	81	93.5
HE6D	Heavy FCC gas,T90con,De Sulf., 60% conv.					0	0	0	0	0	0	0	0	74.7	0.6		49.4	0	7.8	719	5.555	80	91.9
HE7D	Heavy FCC gas,T90con,De Sulf., 70% conv.					0	0	0	0	0	0	0	0	74.7	0.6		53.7	0	8.3	719	5.572	80.3	92.2
HE8D	Heavy FCC gas,T90con,De Sulf., 80% conv.					0	0	0	0	0	0	0	0	74.7	0.6		62.4	0	8.8	719	5.591	80.8	93.4
HE6C	Heavy FCC gas,T90con,DeSulf-Convtnl,60%cv					0	0	0	0	0	0	0	0	78.7	0.6		46.1	0.3	0.8	72	5.458	80	91.9
HE7C	Heavy FCC gas,T90con,DeSulf-Convtnl,70%cv		6.2	1.1	7.3	0	0	0	0	0	0	0	0	78.7	0.6		50.6	0.3	0.8	72	5.475	80.3	92.2
HE8C	Heavy FCC gas,T90con,DeSulf-Convtnl,80%cv			10.8	10.8	0	0	0	0	0	0	0	0	78.7	0.6		58.8	0.3	0.9	72	5.482	80.8	93.4
Summary																							
CARB RFG		899				1.5	7.7	35.2	50.5	55.4	73.7	82.1	89.1	97.7	6.8	2.1	22.9	0.5	4.3	18.8	5.129	84.8	92.7
Arizona RFG			56			1.0	7.4	32.2	42.6	47.2	67.4	76.5	83.5	97.4	6.7	2.1	28.4	0.8	5.6	38.0	5.164	84.1	93.1
Conventional Gasoline				132		3.4	7.1	21.7	38.9	43.9	62.3	70.4	76.4	91.9	7.7	0.3	34.4	0.8	12.4	153.0	5.257	84.1	93.0
Total Pool					1087	1.7	7.6	33.4	48.7	53.6	72.0	80.4	87.2	97.0	6.9	1.9	24.6	0.6	5.3	36.1	5.146	84.7	92.7

Source: ARMS Calibration Results.

Exhibit 12: Summary of Modifications to ARMS for the Calibration Case

Modification	Purpose
Delayed coker -- modify yields	Increase production of coke to match reported volume & increase output of resid blending material
Delayed and Fluid Cokers -- add ratio constraints	Prevent cherry-picking of resid streams for processing and increase coker throughput
Hydrocrackers	
-- add ratio constraints for processing virgin distillate	Prevent cherry-picking of virgin distillate for hydrocracking
-- add ratio constraints for processing gas oils	Prevent cherry-picking of gas oils for hydrocracking
Fluid Cat Cracker	
-- add new modes	Process very low sulfur FCC feeds
-- add new FCC streams & gasoline blendstocks	Represent low sulfur/low olefin FCC gasoline produced from deep hydrotreated feed
-- add ratio constraints for conversion rates	Require similar conversion rates for low and high sulfur FCC feeds
Solvent deasphalter	Represent California operations
-- add new mode & deactivate old modes	
-- add new tar stream	
-- establish new recipe blend for producing resid from tar	
TAME unit -- adjust yields for iso vs normal amylene ratio	Incorporate new technical information
Deep FCC feed hydrotreater -- add new unit	Represent California operations
FCC feed hydrotreaters -- add ratio constraints	Impose ratio on deep and conventional FCC feed hydrotreating operating rates & prevent cherry-picking of feeds between units
FCC Gasoline Hydrotreater	
-- add modes for light FCC gasoline	Represent olefin saturation of light FCC gasoline
-- modify hydrogen consumption	Adjust hydrogen consumption for sulfur & olefin content of FCC naphtha & assumed percent reductions of sulfur & olefin
-- add ratio constraints for light FCC gasoline	Insure that light FCC naphtha is treated, along with medium & heavy FCC naphtha
-- add new streams representing treated light FCC naphtha	Represent characteristics of new, low sulfur/low olefin light FCC naphthas for blending
Distillate hydrotreating	
-- add ratio constraints for virgin feeds	Prevent cherry-picking of heavy naphtha, kerosene, and virgin distillate for desulfurization.
-- add ratio constraints for light cycle oil	Limit desulfurization of light cycle oil and subsequent blending in distillate products

Exhibit 12: Summary of Modifications to ARMS for the Calibration Case

Modification	Purpose
Dependentanizer	Allow depentanization of low sulfur/low olefin FCC gasoline
-- add new modes	Allow depentanization of low sulfur/low olefin FCC gasoline
-- modify yields in existing modes	Account for reported RVP of FCC gasoline
Naphtha splitter	
-- add 250°-300°/300°-325° naphtha splitter	Provide flexibility for T90 control
-- add new reformate modes	Process new naphtha cuts
-- add new benzene saturation modes	Process new medium reformates
-- create new streams for gasoline & distillate blending	Represent characteristics of new reformate and distillate blendstocks
FCC Gasoline Splitting	
-- add new modes for T90 control	Allow for T90 control of new, low sulfur/low olefin FCC gasoline
-- revise existing modes for T90 control	Adjust yields to agree with distillation curve for FCC gasoline from CEC survey
-- add new streams for gasoline blending & hydrocracker feed	Repesent characteristic of new, T90-controlled FCC gasoline and heavy end
Heavy hydrocrackate -- establish a new gasoline blendstock	Allow gasoline blending of high boiling range hydrocrackate consistent with CEC survey
Gasoline blendstocks	
-- modify sulfur contents	Represent sulfur contents reported in CEC survey sulfur content of captive MTBE & TAME
-- modify aromatics content of FCC gasoline and reformate	Represent aromatics contents reported in CEC survey and match gasoline properties
-- modify octane of hydrocrackates	Represent octane reported in CEC survey and increase reformer throughput and severity
-- modify distillation curves	Calibrate to gasoline pool distillation curve based on CEC and API/NPRA surveys
Distillate blendstocks	
-- modify sulfur and aromatics content of desulfurized and dearomatized distillate blendstocks	Calibrate to reported distillate qualities and unit operations
-- modify cetane number of virgin distillate blendstocks and desulfurized and dearomatized distillate blendstocks	Bring cetane numbers in line with information from crude oil assays and calibrate to reported cetane numbers of clear diesel fuel.
-- add distillation properties for diesel fuel blendstocks	Incorporate distillation temperatures in the range reported
-- modify distillation properties for distillate blendstocks	Calibrate to jet fuel and diesel fuel distillation curves reported in surveys
New product categories	
-- add "other distillate"	Represent production of small volumes of heavy, high sulfur content distillate
-- add unfinished oils	Create an outlet for light cycle oils used as cutter stock for residual oil
Predictive Model -- modify coefficients	Reflect MathPro estimates of linear relationships between T50/E200 and T90/E300